THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Toward resilient product-based service supply chains

GABRIELLA GATENHOLM

Department of Technology Management and Economics
Division of Service Management and Logistics
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GABRIELLA GATENHOLM

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Department of Technology Management and Economics
Division of Service Management and Logistics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 6013

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GABRIELLA GATENHOLM
Department of Technology Management and Economics
Division of Service Management and Logistics
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Abstract

Circular economies represent a step toward breaking the linear production model in supply chains. As drivers of enhanced circularity, product-based service (PBS) offerings extend and/or intensify the utilization period of products and thus decelerate the flow of resources. As a result, transitions to PBSs can yield outstanding, sustainable commercial benefits, including minimized resource input into production and the reduction of waste, all without jeopardizing growth. At the same time, PBS settings are highly servitized, entail different flows of people and knowledge, and engender new uncertainties, especially regarding product lifetime and product quality. Although a new way of handling such variation in PBS supply chains involves optimizing logistical tradeoffs, PBS supply chains are subject to uncertainties not only during normal market situations but also during volatile situations, including the COVID-19 pandemic.

This thesis is based on research that followed a qualitative approach using abductive reasoning. Compiling three papers drawing from three studies conducted across several manufacturing industries, the thesis outlines the relationship between circularity and resilience and provides guidance toward realizing resilient PBS supply chains. Study 1 investigated logistical tradeoffs that support enhanced circularity in PBS supply chains, whereas Study 2 probed disruptions and responses in PBS supply chains following a major external event. Last, Study 3 examined the intersection between resilience and sustainability in manufacturing supply chains. The results of those studies in light of findings in the literature underscore three major findings. First, PBS supply chains have to be understood from a wider perspective on logistical tradeoffs (i.e., material versus people, people versus knowledge, and knowledge versus information) added to the traditional logistical tradeoff between material and information in product-based supply chains. Second, the intersection between circularity and resilience showcases the capacity of those logistical tradeoffs to respond to disruptions and thus cultivate resilience in PBS supply chains. That finding highlights the importance of improved local knowledge that is as close to consumers as possible. Third, the thesis provides a framework of three building blocks for developing resilience in PBS supply chains: (i) developing adaptive resilience, related to Mode I of resilience, to alter normal service offering or delivery; (ii) developing transformative resilience, related to Modes 2 and 3, meaning the notion of extending or radically changing the service offering or delivery; and (iii) integrating those dimensions of resilience with sustainability.

List of appended papers

Paper 1

Gatenholm, G., Halldórsson, Á., & Bäckstrand, J. (2021). Enhanced circularity in aftermarkets: Logistics tradeoffs. *International Journal of Physical Distribution & Logistics Management*, 51(9), pp. 999-1021.

An earlier version of Paper 1 was presented at the *Nordic Logistics Research Network* (NOFOMA) conference, held September 17–18, 2020, and published in the *Proceedings of the 32nd Annual Nordic Logistics Research Network Conference*. The paper was also invited to be published in the special issue of the *International Journal of Physical Distribution and Logistics Management* and was presented by invitation in an online session of the 30th annual meeting of *The International Purchasing and Supply Education and Research Association* (IPSERA), held on March 29–April 1, 2021.

Gatenholm was responsible for data collection under the advisement of Halldórsson and Backstrand. The study design was a mutual effort, while data analysis and the paper's planning and writing were performed equally by the first and second authors.

Paper 2

Gatenholm, G., & Halldórsson, A. (2021) Responding to discontinuities in product-based service supply chains in the COVID-19 pandemic: Towards transilience. *Submitted to an academic journal: currently in second review.*

Gatenholm was responsible for data collection under the advisement of Halldórsson. The study design, data analysis, and the paper's planning and writing were performed equally by both authors.

Paper 3

Gatenholm, G., Chari, A., Halldórsson, A., & Stahre, J. (2021) The intersection of industrial resilience and sustainability in manufacturing supply chains. *Proceedings of the 28th Annual European Operations Management Association Conference.*

Paper 3 was presented at the *European Operations Management Association* (EUROMA) 2021 conference, held on July 5–7, 2021, and published in the *Proceedings of the 28th Annual European Operations Management Association Conference*.

Gatenholm and Chari were responsible for designing the study and for data collection under the advisement of Halldórsson and Stahre. Data analysis and the paper's planning and writing were performed equally by the first two authors.

Excluded from the thesis:

Gremyr, I., Backstrand, J., Fredriksson, A., Gatenholm, G., & Halldórsson, A. (2020). Blueprinting construction logistics services to enable quality improvements. *Proceedings of the Annual Logistics Research Network (LRN) Annual Conference 2020*.

The paper was presented at the *Logistics Research Network* (LRN), held on September 9–11, 2020, and published in the *Proceedings of the Annual Logistics Research Network (LRN) Annual Conference 2020*.

Gremyr initiated the paper and designed the paper together with the other authors. All authors contributed to the theoretical aspects and the data collection, which was led by Gremyr. The data analysis and the writing of the paper were done jointly by the authors.

Acknowledgments

I still remember the day that I decided to pursue a doctorate and the moment that I was accepted into the doctoral program at Chalmers University of Technology. I had a dream that, after graduating with a master's of science degree, I would be able to make a real impact in the manufacturing industry, both by working with new strategies and by implementing changes that would lead to a more sustainable world. However, after a few years in the industry, I realized that I would need more knowledge and more power to influence the changes that I envisioned. I wanted a job in which I would learn something new every day and that would challenge my beliefs and ways of thinking—a job in which I would teach and be taught, have stimulating discussions about research and the world, have my intellect challenged, and, above all, develop skills for the future. To that goal, I also realized that earning a doctorate would be the best way forward. Needless to say, it has been a privilege, and I cannot wait to commence my second half toward doctorate.

Certain people have played a major role in making my extremely rewarding, challenging pursuit of a doctorate possible. I would first like to thank my main supervisor, Árni Halldórsson. There is no doubt in my mind that I would not be writing this thesis if it were not for your dedication to me and my research. You have not only been indispensable to my research but also an outstanding friend throughout our years together. Your mind is truly spectacular, and discussing theories, methods, and future research with you has been the most valuable part of my doctoral experience. It has been a true privilege to work alongside you, and I want to thank you for that. You make even the worst days enjoyable! To Ceren Altuntaş Vural, my co-supervisor, thank you for always making time to chat with me, both about research and personal matters. You are a source of inspiration, a woman academic to follow, and a role model to me. To everyone at the Service Management and Logistics division, thank you for being great colleagues and friends.

Nothing in this thesis would have been possible without the support of my husband, Erik. I cannot thank you enough for the person you are to me. You are my greatest inspiration, the light of my days, my soulmate, my partner through anything and everything, and, most importantly, the love of my life. Without you by my side, I would not have dared to leave the industry and pursue a doctorate. Every time that I doubt my capabilities, I only have to reflect on what you would have done, and nothing seems impossible anymore. I love you, both today and forever.

Last, I would like to thank my family. Without your support, I would not be where I am today. Mom and Dad, thank you for everything! You have always supported and loved me unconditionally. Your encouragement and belief in me have made me the person that I am. Victor, my dearest brother, you mean the world to me. I always want you to have a reason to be proud of your little sister, just as I am always proud of you. Your loyalty, thoughtfulness, and warm heart make me a better person.

This is for you, Ademar!

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1

Introduction

Don't judge each day by the harvest you reap, but by the seeds that you plant. – Robert Louis Stevenson

This chapter introduces the research presented in this thesis. After describing the background, the field, and positioning of the research, the chapter articulates the research's scope, purpose, and research questions (RQ) and ends by providing an outline of the thesis.

1.1 Background

During the past 20 years, manufacturing companies have undergone *servitization*—that is, transitioned from traditional supply chains and business models to service-based ones (Paschou *et al.,* 2020). As such, today's manufacturers are no longer merely engaged in transactions from the point of raw materials to point of sale but also support long-term relationships during the in-use phase of products with product-based services (PBS) (Neely *et al.,* 2011). A *PBS* refers to any service for a product offered between the point of sale and the end of its life (Gatenholm *et al.,* 2021). PBSs offer opportunities for companies to transition toward increased servitization and a circular economy by slowing of resource flows (Bocken *et al.,* 2016). Whereas an estimated 80% of manufactured goods are disposed within the first 6 months of their lifetimes (Girling, 2011), enhancing circularity by extending and/or intensifying the utilization period of products can slow down the flow of resources (Bocken *et al.,* 2016). For practitioners, transitions to PBSs provide valuable commercial and sustainable benefits, including 30–60% greater revenues for Original Equipment Manufacturers (OEM)s (McKinsey, 2019). The arguments for PBSs regarding resource efficiency are also compelling given their contributions to reductions in materials needed and used (MacArthur, 2013). Some studies have even suggested that PBSs can decouple customer satisfaction from the consumption of materials and resources (Doni *et al.,* 2019).

Despite the many benefits of integrating PBSs into product offerings, because PBS supply chains generally differ from product-based supply chains in several dimensions, transitioning to PBSs introduces new types of variation into the supply chain. For one, the context is highly servitized and marked by increased attention to the service provider–customer relationship (Baines *et al.,* 2017). For another, the point of sale is not the end point of the supply chain but the starting point, and the customer, service provider, and parts supplier become central actors (Gatenholm *et al.,* 2021). Variation in product lifetimes (Biehl *et al.,* 2007), disperse product locations and wide-ranging volumes (Linton *et al.,* 2007), the unknown quality of products during the in-use phase (Guide *et al.,* 2003), and disparate practices of information sharing and transparency between the focal actors all inject new uncertainties into the supply chain that contribute to new types of variation not experienced in product-based supply chains (Gatenholm *et al.,* 2021). A new way of handling such variation in PBS supply chains is pursuing new logistical tradeoffs between materials (e.g., products and parts) and people, people and knowledge, and information and knowledge, as opposed to tradeoffs between materials and information only pursued in product-based supply chains (Gatenholm *et al.,* 2021).

PBSs are not only subject to the mentioned sources of variation during normal market situations but also sensitive to external disturbances, partly due to their reliance on transformative resources (e.g., people) and the consumers in their particular supply chains (Gatenholm *et al.,* 2021). For instance, when the COVID-19 pandemic forced global shutdowns and social distancing that affected the productivity of

individual organizations as well as entire supply chains (Craighead *et al.,* 2020), disruptions arose given new variation in PBS supply chains, both disruptions with precedent in past experiences and novel disruptions extending beyond the demand and supply sides in the chains (Ivanov & Dolgui, 2020b). In fact, Ernst & Young (2021) have reported that as many as 97% of all industrial product companies have faced disruptions in their supply chains during the pandemic (Harapko, 2021). Because PBS supply chains can afford benefits in normal market conditions and recover from disruptions only if they are resilient (Dubey *et al.,* 2021), the pandemic offers an optimal situation to consider how the principles of circular economies can be put into practice as the global economy recovers. Such practices respond to several calls for local and circular supply chains (Ibn-Mohammed *et al.,* 2020; Nandi *et al.,* 2021) to temper the exposure that today's linear global supply chains face, in logistics arrangements that are failing the planet and its inhabitants (Sarkis *et al.,* 2020).

However, despite considerable interest in supply chain risk and resilience in product-based supply chains, risk and resilience are rarely mentioned in the literature addressing PBS supply chains (Belhadi *et al.,* 2021). Likewise, the literature addressing service management primarily considers risks associated with transitioning from a product- to a service-based company (Zhang & Banerji, 2017), not external risks, which are instead discussed in terms of technological development, digital disruptions, market trends, globalization, and capital management (Benedettini *et al.,* 2015). Even though the literature addressing product-based supply chain risk and resilience identifies means of cultivating flexibility, redundancy, velocity, visibility, adaptability, robustness, and agility as ways of cultivating resilience as well (Ali *et al.,* 2017; Christopher & Peck, 2004; Vanpoucke & Ellis, 2019), it remains unclear whether those strategies are directly applicable and/or sufficient to overcoming disruptions during the in-use phase and in PBS settings. Moreover, all those strategies were developed prior to the COVID-19 pandemic, which has unleashed new disruptions that require the advancement of research on and practices of supply chain resilience (Ivanov & Dolgui, 2020a). Beyond that, other key concerns include ways of not only responding to external threats in the future but also of ensuring that when unforeseen actions occur, their impact and the response are aligned with goals for advanced sustainable development (Schaltegger, 2020). Despite those concerns, practices combining the principles of sustainability and resilience remain underdeveloped (Sarkis *et al.,* 2020; Fahimnia & Jabbarzadeh, 2016).

In sum, PBS supply chains provide significant opportunities to enhance circularity and, in turn, facilitate sustainable development (Bocken *et al.,* 2016). Considering that the climate crisis constitutes a greater threat to the world than COVID-19 (Hussey & Arku, 2020), it is essential to expand understandings on resilient PBS supply chains and their ability to facilitate circularity, for such chains need more resilience given the uncertainties mentioned above, both during normal market situations and during disruptions. Against that background, it is necessary to understand the relationship between circularity and resilience and how the latter will develop after the COVID-19 era in PBS supply chains. Thus, the overall purpose

of this thesis is *to understand the relationship between circularity and resilience and to provide guidance toward realizing resilient PBS supply chains*, as operationalized in two RQs presented hereunder following an overview of the research scope.

1.2 Scope of the research and RQs

Figure 1 provides an overview of the research problem, the different parts of this thesis, their relationships to the RQs and appended papers, the thesis's motivation, and its relevance to the field. All terms are explained in greater depth in the frame of reference (see Chapter 2).

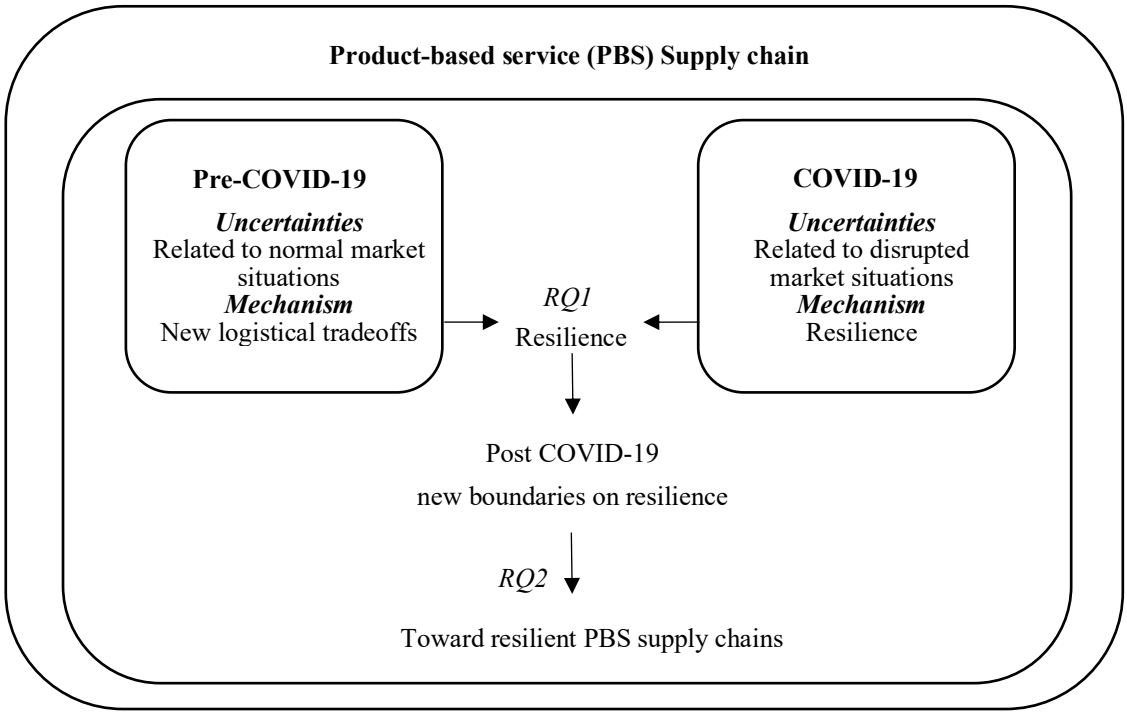

Figure 1. Overview of the scope of the research and the research questions (RQ)

The foreground of Figure 1 presents the context of the studies conducted for the thesis—that is, the PBS supply chain. The box on the left represents PBS supply chains during normal market conditions. Therein, supply chains are subject to numerous new sources of variation in terms of volume, location, and quality. Mechanisms to overcome or regulate such variation include new logistical tradeoffs between materials and people, people and knowledge, and knowledge and information (Gatenholm *et al.,* 2021). However, those tradeoffs were developed to enhance circularity prior to the COVID-19 pandemic, and because the pandemic has since induced the global shutdown of manufacturing plants and national borders and required social distancing that has affected the productivity of individual organizations as well as entire supply chains, such variation has been further complicated by new disruptions (Craighead *et al.,* 2020; Hussey & Arku, 2020). Depicted in the white box on the figure's right-hand side is thus the market situation amid the COVID-19 pandemic, during which disruptions have been introduced as a new type of variation that warrants consideration. The mechanisms to regulate

or even overcome those disruptions include nurturing resilience in the supply chain. Handling uncertainties is therefore pivotal in PBS supply chains, both in normal and volatile market conditions. In that light, RQ1 investigates how enhanced circularity can enhance resilience in PBS supply chains by operationalizing circularity as logistical tradeoffs. The intersection of the two boxes in Figure 1 demonstrates that dynamic, relates it to the first part of the thesis's purpose (i.e., examining the relationship between circularity and resilience), and justifies the first RQ:

RQ1: How do logistical tradeoffs enhance resilience in PBS supply chains?

The COVID-19 pandemic and its consequences have revealed not only the manufacturing industry's ability to handle uncertainties in PBS supply chains but also its limitations. Although RQ1 addresses the impact of logistical tradeoffs on resilience, those tradeoffs cannot alone handle external disruptions such as the COVID-19 pandemic. Indeed, the pandemic has highlighted that PBS supply chains need to be more resilient in the future. In response, some researchers have called for additional studies on supply chain resilience that are more adaptive and transformative (Craighead *et al;* 2020; Wieland, 2021; Wieland & Durach, 2021) as well as advances in the research and practice of supply chain resilience (Ivanov & Dolgui, 2020b). Another key concern is not only responding to external threats in the future but also ensuring that when unforeseen events occur, the response to their impacts maintain, if not advance, sustainable development (Schaltegger, 2020).

Sustainability creates both tensions that challenge resilience and synergies that promote it (Fahimnia & Jabbarzadeh, 2016). In view of that dynamic, new initiatives such as Industry 5.0, the EU's Green Deal (European Commission, 2020), and the Organisation of Economic Co-operation and Development's (OECD) plan to "build back better" emphasize a new way of reasoning that considers resilience. In particular, complementing its precursor Industry 4.0, Industry 5.0 specifically aims to foster research and innovation at the level of service to promote the transition toward a sustainable, human-centric, resilient European industry (European Commission, 2021). Meanwhile, the action plan proposed by EU's Green Deal prioritizes sustainability and proposes that building up resilience is an important mechanism for achieving net zero emissions and a climate-neutral future in the EU by 2050. Last, the OECD's plan to "build back better" aims to reduce the likelihood of future shock, to promote resilience when they occur, and to further align those strategies with long-term goals for reducing emissions, slowing the loss of biodiversity, and increasing the circularity of supply chains (OECD, 2020). Considering all of the above, RQ2 seeks to understand how those new boundaries affect PBS supply chains, as part of an effort to develop a conceptual framework of building blocks of resilience in the chains. In doing so, RQ2 addresses the second part of the thesis's purpose—that is, building blocks that provide guidance toward developing resilient PBS supply chains.

RQ2: What new building blocks of resilience are required in PBS supply chains?

1.3 Research setting and delimitations

The research conducted for this thesis encompasses various fields. Its starting point is in the literature on supply chain management and service management specifically focused on circularity and slowing of resource flows by including services in product offerings. However, given its focus on resilience both before and during the COVID-19 pandemic, the research also draws from work on supply chain risk and resilience. From a broader perspective, the research additionally addresses the fields of logistics, reverse logistics, closed-loop supply chains, and sustainable supply chains, whose overlaps allow studying circularity and resilience from the perspective of PBS supply chains. The composition and evolution of the thesis also reflect the world's current developmental trajectory, by first focusing on servitization and sustainability but increasingly moving toward resilience in order to meet the demands of relentless disruptions such as the COVID-19 pandemic.

The thesis's findings need to be viewed in light of some delimitations, one of which stems from collection of empirical data, which were gathered only from personnel at different OEMs, not from customers, consumers, logistics providers, or other potential service providers. Thus, the thesis takes the perspective of the OEM as the owner of the problem and the actor that could most benefit from the research given their potential to significantly impact both the transition towards circularity and enhancement of resilience in the PBS supply chain. Last, although the thesis primarily focuses on the Swedish market, most respondents were from large international organizations.

1.4 Outline

Following this introductory chapter, which has explained the topic, background, setting, purpose, and RQs of the research conducted for this thesis, Chapter 2 provides a frame of reference, starting with an overall framework that situates the appended papers in the field and ends by synthesizing with a theoretical framework. Next, Chapter 3 describes the research's position and design, including in terms of data collection, data sampling, data analysis, and research quality, and presents the timeline of the research. Chapter 4 summarizes the three appended papers, after which Chapter 5 discusses the results in light of the literature as a means to answer the two RQs. Last, Chapter 6 concludes the thesis by articulating its contributions to the literature and by providing directions for future research.

2

Frame of reference

The only stable thing is that everything changes. – Heraclitus

This chapter identifies and positions the key concepts and theories guiding the research conducted for this thesis. The underlying motivation of this chapter is to describe the research's theoretical underpinnings and connect the different strands of the literature contributing to its position.

2.1 Overview

This thesis contributes to two fields—supply chain management and service management—as shown in Figure 2.

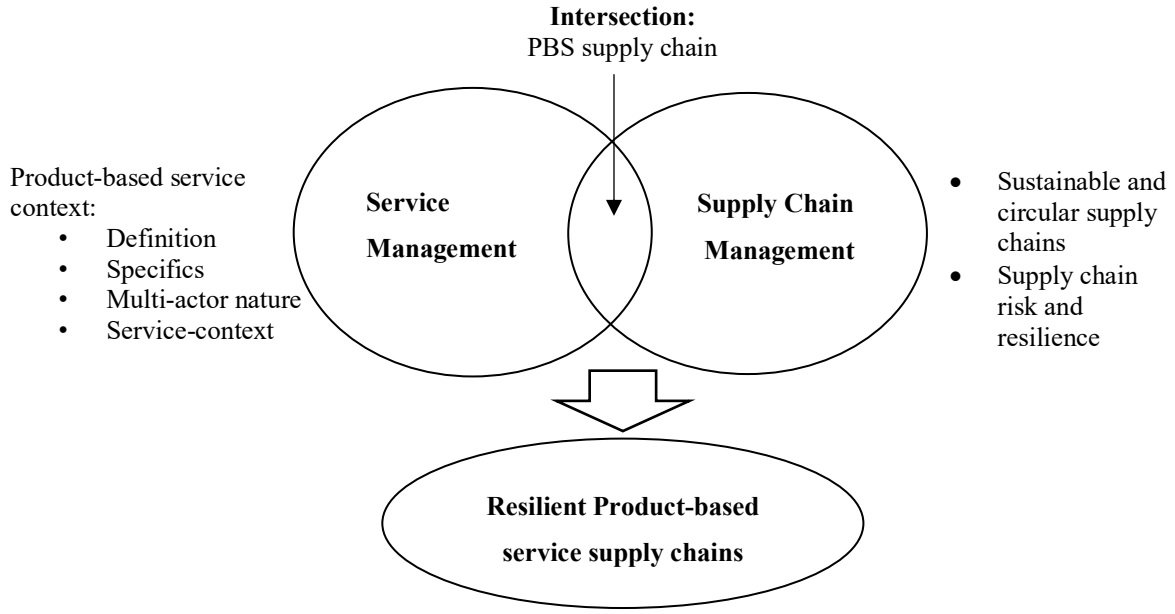

Figure 2. Frame of reference and position of the research

This section provides an overview of the relevant concepts within those two fields, namely the PBS context, sustainable and circular supply chains, PBS supply chains, and supply chain risk and resilience, and synthesizes them to develop a theoretical framework for resilient, sustainable PBS supply chains.

2.2 Sustainable and circular supply chains

Although the COVID-19 pandemic induced a steep reduction in air pollution in advanced economies in 2020, primarily due to reduced economic activity owing to global lockdowns (Le Quéré *et al.,* 2020), the impact has been temporary and does not a reflect a change in the global economy or economic structure (Le Quéré *et al.,* 2020). Because the impact is not due to new decisions made or new policies implemented, it will not be sustained after the pandemic (Ibn-Mohammed *et al.,* 2020).

The current linear model of production and consumption within manufacturing industries puts a strain on Earth's already limited resources and exacerbates climate change, the loss of biodiversity, and other major challenges for sustainability (Khan *et al.,* 2021). To counter that and other sources of strain, the United Nations, based on its previous Millennium Development Goals, proposed 17 new Sustainable Development Goals to be achieved by 2030, including one to ensure sustainable production and consumption and another to take climate action (United Nations, 2016). In supply chains, sustainable development aims to enhance the overall sustainability-related performance of the chains in terms of the

triple bottom line—that is, environmental, social, and economic impacts (Khan *et al.,* 2021). To be sure, most efforts toward achieving sustainability in supply chains have been directed at reducing their environmental impacts, primarily measured in terms of greenhouse gas emissions and resource consumption (Varsei *et al.,* 2014). In parallel, efforts toward social sustainability have focused on reducing risks to human health, communities, and society at large (Boukherroub *et al.,* 2015), whereas ones targeting economic sustainability have sought to reduce the total cost of supply chains (Mari *et al.,* 2016).

To achieve the mentioned Sustainable Development Goals and boost the overall sustainability-related performance of supply chains, circular economies, viewed as a complete or at least partial solution, have gained traction (Bocken *et al.,* 2016). As for the origins of the circular economy, Turner *et al.* (1989) has described the system as a way to minimize the resources put into production, as well as reduce waste, emissions, and energy leakage, and, as a result, lower or even eliminate the environmental impact without jeopardizing growth (Bocken *et al.,* 2016; MacArthur, 2013; Nußholz, 2018). Since Turner *et al.*'s work, several authors (e.g., Antikainen & Valkokari, 2016; Bocken *et al.,* 2016; Chesbrough & Rosenbloom, 2002; De Angelis *et al.,* 2018; Geissdoerfer *et al.,* 2018; Osterwalder & Pigneur, 2010) have proposed business model innovation to be a key tool for implementing circular economic practices and effecting changes in organizations and in systems such as supply chains. From the other direction, Geissdoerfer *et al.* (2018) have stressed that supply chains are particularly important in designing circular business models. Beyond that, they have used the term *circular supply chain management* to describe a strategy of narrowing, slowing, and closing resource loops, three dimensions developed by Bocken *et al.* (2016) and further subdivided into circular product design strategies and circular business model strategies. For one, narrowing entails the dematerialization of products by design and prescribes that materials should be avoided in the first place—that is, before production (Bocken *et al.,* 2016). For another, tactics for closing resource loops have been examined in fields such as reverse logistics and in settings such as closed-loop supply chains, often with an emphasis on take-back programs and recycling. However, closing resource loops by recycling generally leads to the downcycling of materials, which induces major losses in the value of resources (Jørgensen & Remmen 2018), and does not benefit the environment as much as slowing resource flows.

In that and other ways, slowing resource flows is distinct from the other two strategies, one that relates to all actions taken to prolong the lifetime of products and materials, typically in the design phase but also in the business model design and supply chain (Bocken *et al.,* 2016). Whereas business models are determined before the point of sale, the supply chains that support the deceleration of resource flows supports the service flow after the point of sale during the in-use phase. Those services, termed *PBSs*, aim to preserve the embodied value of the entire product, parts, and materials for as long as possible (Bocken *et al.,* 2016; Jørgensen & Remmen 2018). PBSs are therefore integral in circular economies and considered to be popular tools by manufacturing firms around the world for enhancing the longevity

of resources and achieving sustainability (Blomsma & Brennan, 2017). That dynamic is in line with the notion of circularity, which advocates developing circular processes to preserve the value of products, component, and/or materials by keeping them in use longer via repair, reuse, remanufacture, and recycling (Blomsma & Brennan, 2017; den Hollander *et al.,* 2017).

2.3 PBS supply chains

This thesis defines the *PBS supply chain* as comprising all services related to a product during its in-use phase—that is, after the point of sale but before its disposal. Figure 3 illustrates the PBS market, which encompasses the product during its use-phase and all actors involved in providing PBSs.

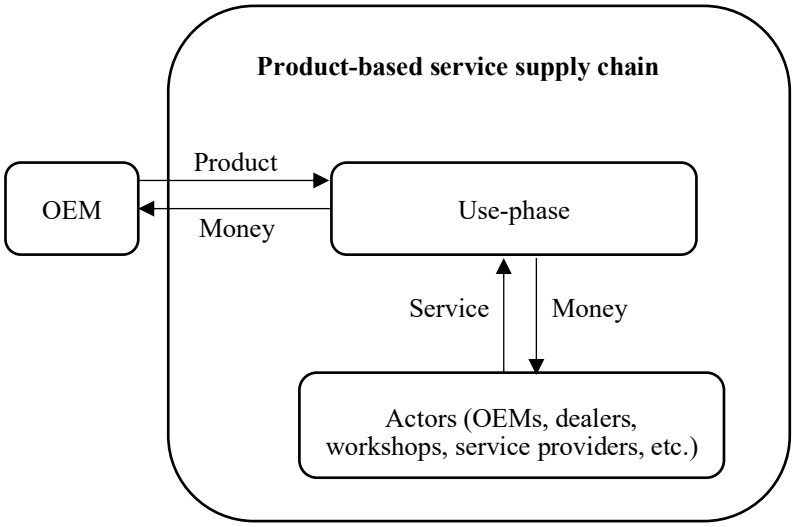

Figure 3. The product-based service supply chain

The starting point of the PBS is at the point of sale, either directly from an Original Equipment Manufacturer (i.e., OEM) or from a retailer or distributor. In this thesis, the starting point is at the OEM, because the thesis takes an OEM-based perspective and investigates OEMs that sell products to customers either directly and therefore act as the service provider or indirectly via retailers or distributors that thus act as the service provider. By extension, *service providers* are defined as actors that provide product-related services in exchange for money during the in-use phase of products; in this thesis, all service providers are affiliated with the OEM.

Because PBS supply chains focus on the in-use phase of products during their lifetimes, they pose new requirements for supply chains that traditional product-based supply chains cannot necessarily meet. For one, PBS supply chains depend heavily on the sustained supply of parts, people, and products as key resources in delivering service offerings (Gatenholm *et al.,* 2021; Farris *et al.,* 2005). For another, they are networks of not only traditional supply chain actors (e.g., suppliers, OEMs, and customers) but also additional actors such as dealers, workshops, charging stations, and third-party apps. Beyond that, PBS supply chains require the coordination of manufacturing systems, maintenance, the distribution of spare parts, logistics systems, remanufacturing operations, customer support, the sale of accessories,

assistance from field technicians, and customer care, among other components (Durugbo, 2020). Third, the context is highly servitized, with increased attention to the service provider–customer relationship (Baines *et al.,* 2017; Neely *et al.,* 2011). As a result, the risk of cost is shifted from the customers to the providers, because the providers have promised an intangible result to customers, not merely a tangible product (Reim *et al.,* 2015). Last, customers are central players in PBS supply chains. They not only create the service demand (Tran & Kummer, 2015) and contribute direct feedback to providers (Brax, 2005) but also become a crucial part of service offerings, because the services are often co-produced with providers (Tran & Kummer, 2015). The customers thus become operators in several diverse roles, who help to design services, monitor quality, provide information, and even self-service their products (Sampson & Spring, 2012).

2.4 Risk and resilience in PBS supply chains

Formulated in the 1970s and first introduced in ecology, the notion of *resilience* is defined as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973). By extension, building on resilience engineering, *supply chain resilience* has been defined by several authors as a supply chain's ability to withstand changes in the steady state and return to the original or a new desirable state (Carvalho *et al.,* 2012; Christopher & Peck, 2004; Erol *et al.,* 2010). Although defining *resilience* in that way is common and, in some cases, sufficient for product-based supply chains, such definitions do not capture the complete scope of resilience in PBS supply chains, which prioritize the customer's perspective to a greater degree. Likewise, the concepts of risk and resilience in supply chains have commonly focused on supply chains for manufactured goods—that is, product-based supply chains from raw materials to the point of sale. No matter the type of supply chain, however, understanding the concept of supply chain resilience first requires understanding the risks and uncertainties in the chain.

2.4.1 Uncertainties in PBS supply chains

As highlighted in the literature on PBS supply chains, variations in PBS supply chains never before experienced in product-based supply chains have given rise to new uncertainties. First, variation in the lifetime of products now complicates how service providers in PBS supply chains have to plan and structure their chains (Linton *et al.,* 2007; Nußholz, 2018; Werning & Spinler, 2020). Second, the quality of products differs depending on usage, maintenance, and production (Guide *et al.,* 2003; Linton *et al.,* 2007). Third, because the lifetime and quality of products differ, their volume in the supply chain remains uncertain, which prevents providers from gaining a full overview of the volume of products present in their PBS supply chains (Biehl *et al.,* 2007). Fourth, during the in-use phase, products are located with customers and thus scattered across potentially great distances (Biehl *et al.,* 2007; Linton *et al.,* 2007), which creates difficulties for service provision and, in turn, casts all of those small actors—

the customers—in a leading role in supply chains (Tran & Kummer, 2015). Fifth, the engineering knowledge and/or knowledge about service provision required to perform and develop services present another uncertainty in PBS supply chains, since the service personnel may not be the same for each delivery (Hernandez *et al.,* 2018). Sixth, the organizations priorities and available resources postulate an uncertainty for PBS services as they may not be considered vital to the organization (Hernandez *et al.,* 2018). Yet, PBSs are a crucial factor not only for business performance but also for entire industries and thus some societies, especially ones in which PBS offerings and delivery sustain the transport industry, as bitterly experienced during the COVID-19 pandemic (Ibn-Mohammed *et al.,* 2020). Last, uncertainties in information and limited transparency between actors given the large number of specific customers in PBS supply chains create additional uncertainties (Cohen *et al.,* 2006; Farris *et al.,* 2005). All of those new uncertainties for supply chains created by PBS offerings, summarized in Figure 4, need to be addressed.

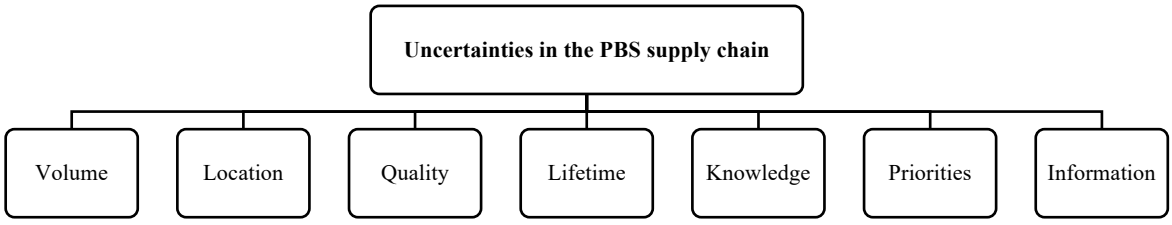

Figure 4. Uncertainties in product-based service (PBS) supply chains during normal market situations

Even then, all of those uncertainties derive from the unreliable notion of stable market settings. Because the global market is not always stable and because PBS supply chains are highly sensitive to external disturbances (Arlbjørn *et al.,* 2011; Vilko & Ritala, 2014; Wang *et al.,* 2015), they present still other uncertainties. Nevertheless, literature on PBSs addressing risks associated with external factors is scarce and primarily explores decisions related to inventory ordering under service constraints (Wang *et al.,* 2015) or establishing relationships between service suppliers and end customers (Åhlström & Nordin, 2006). Although Tran and Kummer (2015) have also discussed risks in service supply chains, those risks concerned pure services (e.g., financial services), not ones associated with products in general, and the services in and of themselves, not as components of supply chains. However, risks in PBS supply chains cannot be viewed exclusively at the level of the firm but involve a network of organizations in various processes and activities that offer customers value embodied in products and services.

Although the risks in the literature on product-based supply chains are also relevant to PBS supply chains, the emphasis is on smaller events that affect either demand or supply and have a decreasing rippling effect following the initial shock (Ali *et al.,* 2017). In that light, notions of supply chain risk have developed from the notion of the bullwhip effect (Chopra & Sodhi, 2014) and evolved from perspectives on external risks related to supply chains—for instance, related to supply and demand—to

include not only risks related to internal control and processes but also external environmental risks beyond the control of supply chains (Christopher & Peck, 2004). On top of that, the globalization of supply chains, with their increased focus on efficiency, pricing, and single sourcing, has introduced another set of new risks (Pettit *et al.,* 2019). Today, being lean and globalized in supply chains, as most companies are, makes them specifically prone to major disruptions (Ivanov, 2020).

Along with the importance of understanding external risks in PBS supply chains, it is also necessary to better understand what disruptions may occur in those chains and how companies can implement strategies to cultivate resilience and manage both daily and exceptional risks therein (Tran & Kummer, 2015). For instance, service providers that depend heavily on the movement of people are presumably the first to be impacted by disturbances such as the COVID-19 pandemic (Belhadi *et al.,* 2021). Furthermore, future major threats, including other pandemics, can be expected to differ substantially from typical disruptions experienced in supply chains in terms of scope, spillover, and shifts (Craighead *et al.,* 2020). For one, typical disruptions such as natural disasters and labor strikes are usually regional in scope and/or contained within one industrial sector. For another, they are often initiated by a shock that causes rippling effects that eventually dissolve, and they primarily relate to disruptions in either demand or supply. Major threats such as pandemics and other potential crises, however, may cause initial shocks that do not dissolve due to the presence of multiple aftershocks. Those threats are also liable to span multiple regions and/or industries as well as to affect both supply and demand at the same time.

2.4.2 Resilience in PBS supply chains

The literature on resilience in service supply chains in general and on PBS supply chains in particular is scarce and rather underdeveloped (Ostrom *et al.,* 2021; Arlbjørn *et al.,* 2011; Vilko & Ritala, 2014; Wang *et al.,* 2015). Among authors who have touched upon resilience in service supply chains in relation to product-based supply chains, Vilko and Ritala (2014) have distinguished features of the two types of chains and elaborated on strategies to handle intangible resources during what they refer to as *real-time activities*. All things considered, they proposed that those strategies should be less statistical and more intuitive and proactive. From another perspective, Åhlström and Nordin (2006) have emphasized the importance of the manufacturer–supplier–customer, relationship in developing resilience, and flexibility has also been underscored as being vital to the capacity of product-service supply chains to cope with uncertainties (Sundin & Bras, 2005; Georgiadis & Athanasiou, 2013). All of those findings, however, stemmed from the context of pure service supply chains that do not involve any products.

Despite the scarcity of literature on resilience in PBS supply chains, because such chains consist of two parts—the product-based and the service-based parts—lessons for the chains can still be learned from the literature on resilience in product-based supply chains. Early on, Caniato and Rice (2003) argued that the most important resilience-related capabilities for firms are flexibility and redundancy, which

have since been subdivided into concepts such as agility (Christopher & Peck, 2004), responsiveness (Carvalho *et al.,* 2011), collaboration (Scholten & Schilder, 2015), visibility, and information sharing (Zhu et al., 2018), as well as concepts such as risk management (Chopra & Sodhi, 2014). At the same time, Tang (2006) have encouraged OEMs to have a multiplicity of sources and to practice risk sharing amongst actors. Such advice aligns with what Chopra and Sodhi (2014) have argued, namely that ensuring redundant suppliers can help to achieve supply chain resilience, which Vanpoucke and Ellis (2019) have also supported with the additional recommendation of ensuring inventory buffers and backup sources. From another angle, in their comprehensive review of 140 peer-reviewed publications on managing risk in supply chains, Ghadge *et al.* (2012) have distinguished proactive from reactive strategies: the former being related to measures taken before disruptions and the latter being related to measures taken during disruptions. Although those strategies have both a product-based focus and overlaps with PBS supply chains, for they are both based on the flow of products and parts (Gatenholm *et al.,* 2021), the strategies do not accommodate the service-based dimension of PBS supply chains.

Since the outbreak of COVID-19, new calls have been issued for more comprehensive resilience-oriented strategies that foster a combination of traditional resilience and transformability (Craighead *et al.,* 2020; Ivanov, 2020; Ivanov & Dolgui, 2020b; Mollenkopf *et al.,* 2020). Those calls follow the work of Ali *et al.* (2017), who have argued that the literature on resilience in supply chains emphasizes a chain's ability to recover and adapt at the expense of addressing transformability. More recently, Wieland (2021) has also called for research on resilience that addresses both adaptive and transformative resilience and thus fosters *transilience*, defined as "the ability to simultaneously restore some processes and change—often radically—others (Craighead *et al.,* 2020). Several other authors have argued for adaptive supply chains able to handle the disruptions of the future once the COVID-19 pandemic subsides (Wieland & Durach, 2021; Wieland, 2021) and specified that supply chains can be better understood when interpreted as complex adaptive supply networks, not static, linear supply chains. To that end, Wieland (2021) has introduced the concept of panarchy theory as a means to achieve resilient adaptive supply networks. That concept, as well as transilience, aligns with the idea of socioecological resilience (Gunderson &Holling, 2002), which, unlike traditional engineering resilience, does not seek to restore the preexisting equilibrium following disruptions but promote functional existence via continuous transformation (Wieland, 2021).

Nevertheless, because it is unclear how the two dimensions of transilience—that is, resilience and transformability—should be conceptualized (Craighead *et al.,* 2020), it remains necessary to understand how companies can restore some processes while simultaneously transforming others, sometimes radically. From a conceptual standpoint, those calls converge in the development of PBS supply chains given their emphasis on collaboration and transformability in line with service development. Developing services should occur jointly with customers and be continuously performed as demand changes (Morgan *et al.,* 2019). Because such flexibility requires adaptive supply chains able to both adapt to

changes and improve during the process, the literature and recent research may not be sufficient to meet future risks similar to those experienced during the COVID-19 pandemic.

2.5 Sustainability and resilience in PBS supply chains

In line with the call for new research on resilience, several authors have also called for pursuing resilience in combination with sustainability (Fahimnia & Jabbarzadeh, 2016; Negri *et al.,* 2021; Zavala-Alcívar *et al.,* 2020). Although resilience has become increasingly important since the COVID-19 pandemic, the need for sustainability has not lessened but only intensified and needs to be included in designs for resilience (Zavala-Alcívar *et al.,* 2020). Rebuilding the global economy due to the COVID-19 pandemic presents the opportunity to build back better, in accordance with the OECD (2020), in which objectives related to resilience have to be aligned with three dimensions of sustainability—that is, the environmental dimension, the social dimension, and the economic dimension (Zavala-Alcívar *et al.,* 2020). Regarding the economic dimension, responses to short-term threats such as resource scarcity must align with responses to the long-term threats of the environmental dimensions in terms of climate change (Ruiz-Benitez *et al.,* 2017). However, sustainability and resilience typically operate at different paces and following different agendas; whereas resilience primarily emphasizes short-term adaptive changes, sustainability operates from a long-term strategic perspective (Redman, 2014). On top of that, the economic dimension of sustainability usually takes priority over the other dimensions as well as resilience (Sarkis *et al.,* 2020).

Even so, promoting economic sustainability can positively impact both resilience and environmental sustainability. Decreased costs of production and materials as well as decreased waste can improve resilience and at once improve the environmental sustainability-related performance of supply chains (Ruiz-Benitez *et al.,* 2017). Fahimnia and Jabbarzadeh (2016) have argued, however, that the total cost of a supply chain increases if the sourcing, production, and distribution are made to be more resilient and environmentally friendly. Implementing information control systems and technology, by contrast, has been shown to improve both resilience and sustainability. Ruiz-Benitez *et al.* (2017) have recommended information control systems able to improve information sharing between customers and suppliers as a means to enhance resilience and sustainability. Added to that, Ju *et al.* (2020) have argued for integrating green suppliers, which can improve practices of both proactive and reactive resilience, while Nandi *et al.* (2021) have highlighted the localization of supply chains and Govindan *et al.* (2014) have argued for disaster planning for social sustainability and resilience. Nevertheless, resilient supply chains are characterized by immense capacity in terms of buffers, inventory, and time (Rajesh, 2018), which directly contradicts the widespread ideal of minimizing waste as an essential part of achieving green, environmentally friendly supply chains (Raut *et al.,* 2021). Moreover, strategic stocks, inventory buffers, and increased production times can be expected to increase the overall cost of supply chains (Fahimnia & Jabbarzadeh, 2016). Thus, amid both synergies and tensions between resilience and

sustainability, it remains unclear how those two vital forces relate, hence calls for identifying new building blocks for resilience that takes a sustainability-oriented perspective in PBS supply chains post-COVID-19 (Zavala-Alcívar *et al.,* 2020).

2.6 Synthesis: Toward resilient PBS supply chains

In sum, several trends urge further research on resilience in PBS supply chains. First, PBS supply chains play an important role in society by promoting both circularity and its societal relevance and by supporting products in use, that may play an important role in society. Examples include transport and health care equipment, which during pandemics are crucial to a country's infrastructure and survival. Second, gaps exist in literature on risk and resilience in relation to PBS supply chains, including about the service dimension of the supply chain. Cultivating resilience amid supply chain risks has tended to take a product-based focus and does not consider the service dimensions of PBS supply chains, Third, while, current literature may grasp the product dimension of the PBS supply chain, there are also new calls that current supply chain resilience practice and research on product-based supply chain does not fully grasp the severity of more extensive disruptions such as the COVID-19 pandemic. Fourth, supply chain resilience and sustainability have been treated in different streams of research and practice that need to be aligned moving forward. Therefore, this thesis seeks to provide guidance toward resilient PBS supply chains by identifying building blocks of resilience to meet external disruptions, such as the COVID-19 pandemic in the future and to work toward a more sustainable development. Building blocks of resilience in PBS supply chains are viewed as a means to handle uncertainties in the chains, which corresponds to the research's purpose, *guidance toward achieving resilience in PBS supply chains*, and serves as the basis of RQ2.

3

Methodology

The way to get started is to quit talking and begin doing. – Walt Disney

This chapter describes the overall design and approach of the research conducted for this thesis and how the design and approach relate to the RQs, and the studies performed. In closing, the chapter also discusses the research's quality, validity and process.

3.1 Research position

In the research conducted for this thesis, no absolute truth was assumed or sought, and I, the researcher, was not independent from the study. Along similar lines, although the research focused on interactions between resilience and circularity and how services can be designed to enhance circularity and resilience by involving humans in PBS supply chains, it did not seek ways to control them. The research therefore adopted a largely realist view, especially one based on considerations of critical realism, which observes a distinction between realist ontology and constructivist epistemology (Maxwell, 2012a). Critical realists argue that reality is in fact real and exists independently of human thoughts and beliefs. They also hold that social objects and phenomena, whether external to or independent of individuals, affect how people perceive their worlds, whether they are aware of it or not (Niiniluoto, 2002; Sayer, 1999). As a result, critical realism maintains that, given the absence of regularity in each social setting, the same mechanism can produce different outcomes based on the context in which it operates (Sayer, 1999). According to that logic, each PBS supply chain and its actors are unique to each setting, each of which contains multiple actors, and results found from studying such chains are potentially true for other similar settings. However, unlike in positivist approaches, no absolute truth exists in critical realism. Thus, as is typical in critical realism, the research investigated what *could* be the case, not what *must* be the case (Maxwell, 2012a).

Based on fundamental assumptions of the ontological view (i.e., one's view of the world) and the epistemological view (i.e., how one gains knowledge from the world; Rawnsley, 1998), I initially began the research process with a positivistic view and thus sought to objectively observe phenomena as much as possible to create meaning and gain knowledge. However, I soon realized that disregarding the subjective influence of humans was impossible. After all, no systems examined in my research—that is, the constellations of actors involved in PBS supply chains—are purely technical, for they also involve humans. Indeed, they are multi-actor settings that are unique for each customer. I also realized that the various studies in which I was involved were using multiple methods of data collection to meet their objectives. Thus, I positioned my philosophical view of the scientific world with reference to the pluralistic realities of the pragmatic approach (Creswell, 1998). The pragmatist worldview (Kaushik & Walsh, 2019) allows researchers to choose between a range of methods that work best for the situation at hand, thereby making it practical and allowing for the inclusion of subjective and objective values and facts (Creswell, 1998). Although a worldview most often taken in mixed-methods research, it was also best suited for the research conducted for this thesis, because it afforded me, as the researcher, the freedom to focus on the research problem or question, not the method being used to address that problem or question. In addition, that view of the world allows for words and thoughts to operate as tools for solving problems, instead of prescribing theory and methods to guide the research. It is a practical worldview that reflects the external environment, acknowledges the need for research, and enables practically solving problems at hand. Because my research was heavily influenced by a changed market

landscape due to the COVID-19 pandemic, those changes also affected how I conducted the research. At the same time, I did partly rely on a constructivist worldview (Schwandt, 1994) in some sense, for I believe that individuals seek to understand the world in which they live and work and that my role as a researcher is to make sense of that understanding. However, all told, for my research context as the PBS supply chain in a starkly changed market and world during the past two years, the pragmatic worldview best explains how I conducted the research.

3.2 Research design

The design of any research should relate to the purpose and RQs of the research project (Maxwell, 2012b). The research conducted for this thesis investigated PBS supply chains during both normal and volatile market situations and sought to understand how companies can enhance resilience in their PBS supply chains. Although that dynamic has neither been thoroughly examined nor well-defined in any particular field, the particular phenomenon of resilience in PBS supply chain spans various fields of research, as well as in the interface between them, which in turns calls for collecting rich empirical data to expand current understandings of the phenomenon (Edmondson & McManus, 2007). Maxwell (2012b) has also underscored the importance of aligning a research project's RQs, objectives, conceptual framework, method(s), and measures of validity. Along those lines, the research conducted for the thesis was exploratory in nature and did not seek to find the absolute truth but rather to interpret trends and activities as a way to identify patterns and behaviors that could succeed in the setting. Because the aim was to explain what is not entirely clarified in the literature and to gain a deeper understanding of a relatively unexplored topic, it seemed natural to rely on a qualitative approach instead of a quantitative one (Bell & Bryman, 2018; Maxwell, 2012b). Maxwell's (2012b) well-established approach to designing qualitative research was used as a basis for the research design followed for this thesis, which appears in Figure 5.

The method for the research positions the RQs at the center of the design, which represents the heart of the model and connects directly to all four other components in the design: the research objectives, the theoretical framework, the research method, and the measures of validity. Likewise, Maxwell's (2012b) approach considers RQs to be not the starting point but rather the center of the research and thus directly connected to the other components of the research design and directly influences all decisions made regarding the design. At the same time, the RQs do not need to be firmly stated from the outset of the research but can be reevaluated as it proceeds. In the research presented here, that approach was suitable because the RQs were not concrete when I began my doctoral work, after which the external market environment changed tremendously due to the COVID-19 pandemic, and because the topic of PBS supply chains is rather undeveloped. Again likewise, Maxwell's (2012b) research design emphasizes that researchers should reiterate their purpose and RQs based on the external environment.

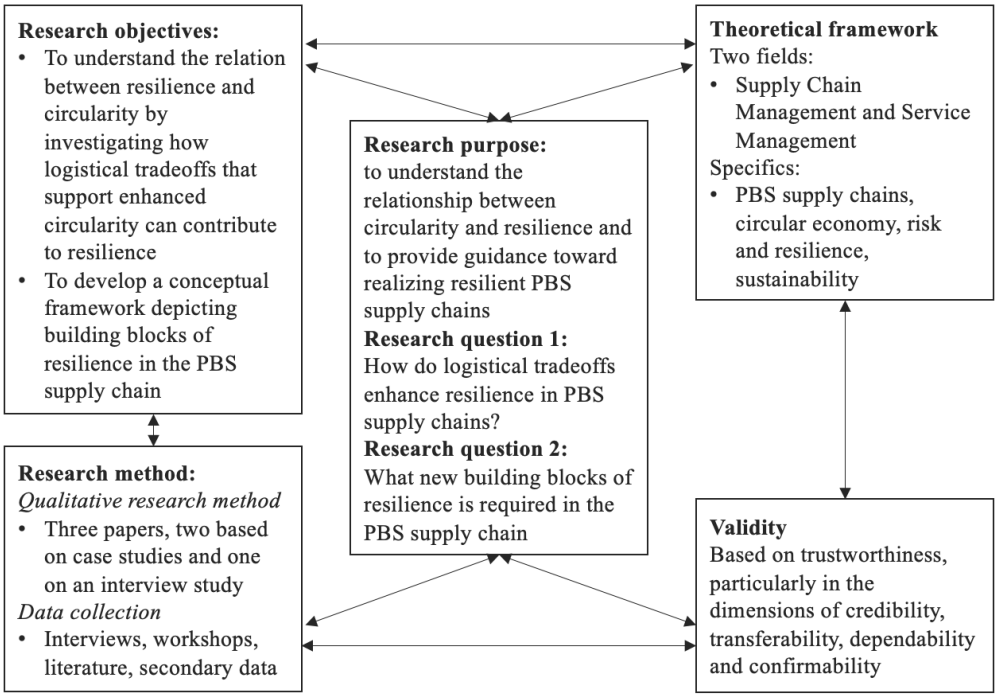

Figure 5. The design of the research, based on Maxwell (2012b)

Gathering all of those considerations together, Figure 5 describes the major components of the research—its objectives, purpose, and RQs—all derived from Chapter 1 of the thesis. The method is further explained in Sections 3.1–3.3, after which validity is addressed in Section 3.4, in which the research quality is judged based on four criteria. The purpose of the thesis was fulfilled by answering two RQs in three studies, each with a corresponding paper. Conducted between early 2019 and mid-2021, each study contributed to answering at least one of the RQs. The relationships between the RQs, the three studies, and the three papers are illustrated in Figure 6.

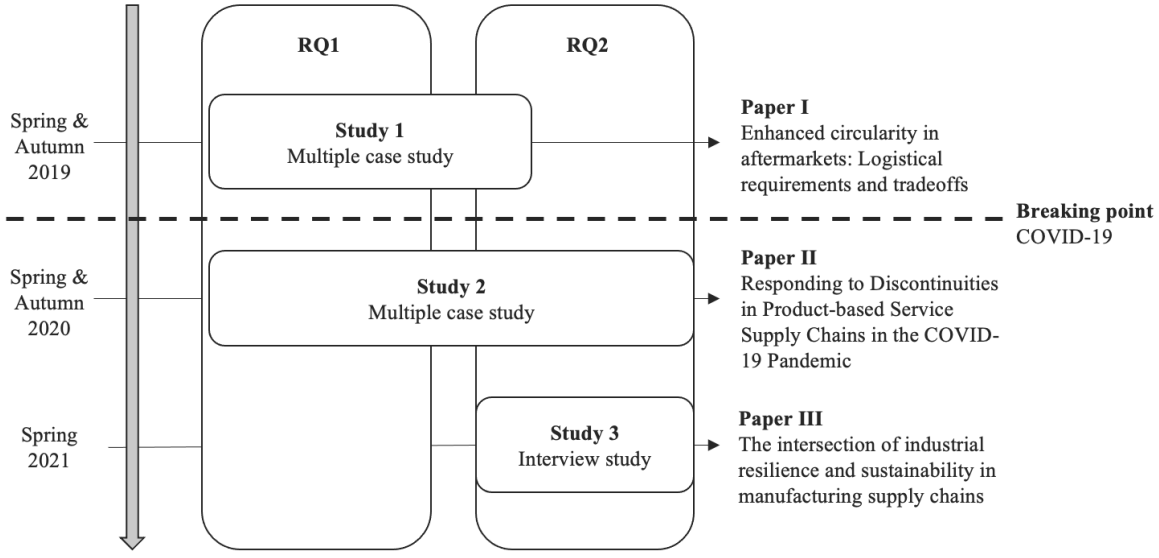

Figure 6. The studies conducted for the thesis in relation to the research questions (RQ) and the corresponding papers

In line with that interactive research design (Maxwell, 2012b), the RQs were reevaluated several times, which proved crucial as the COVID-19 pandemic steered the research in a new direction. For simplicity's sake, the beginning of the new direction is presented in Figure 6 as the breaking point, before which Study 1 was performed and after which Study 2 commenced, namely when COVID-19 was declared a pandemic in March 2020. Whereas Study 1 focused on PBS supply chains during normal market situations, Studies 2 and 3 focused on resilience in those supply chains. Added to the pandemic, new initiatives such as Industry 5.0 also influenced the research's alignment of resilience and sustainability, as brought to light in Study 3.

3.3 Studies and methods

The research design and methods of the three studies conducted for the thesis, each of which corresponds to an appended paper, are detailed in Table 1.

Table 1. Research design and methods adopted in the three papers

Study	Paper	Methods of data collection	Methods of data analysis
Study 1: Multiple-case study on logistical tradeoffs	Paper 1	Interviews, industry workshop, and literature review	Exploratory analysis, cross-case analysis, and theory development
Study 2: Multiple-case study on transilience in PBS supply chains	Paper 2	Interviews, secondary data, industry workshop, and literature review	Exploratory analysis, thematic analysis, cross-case analysis, and theory development,
Study 3: Interview study on resilience and sustainability	Paper 3	Interview and literature review	Exploratory analysis and theory development

Whereas Studies 1 and 2 addressed the in-use phase of products and thus PBS supply chains, Study 3 was explorative and partly sought to outline a foundation for further research to be conducted after the thesis on the intersection of resilience and sustainability in PBS supply chains. Likewise, Paper 3 takes a broad perspective on the complete value chain to understand recent literature and industry perspectives on the two concepts. All studies involved multiple methods of data collection, and aside from interviews with multiple respondents, additional data were gathered via industry workshops, webpages, and conference presentations for additional evidence from a single setting in a certain context. All interview questions were open-ended, which allowed for inquiries into what I, as the interviewer, did not know in order to ensure that the interviewees could elaborate freely on the phenomenon studied. In all, those qualitative ways of collecting data were more suitable for the studies than quantitative ones (Flick, 2014).

Reported in Papers 1 and 2, respectively, Studies 1 and 2 were case studies, which follows Aastrup and Halldórsson's (2008) argument that supply chains benefit from case studies because the logistics structures forming the chain have material and non-material elements. The same logic holds for PBS

supply chains, which are based on tangible and non-tangible resources. As a result, the case studies were able to yield in-depth data in terms of supply chain activities and performance (Aastrup & Halldórsson, 2008). Paper 3, by contrast, is based on a literature review and an interview study, which was deemed appropriate because more open-ended questions were needed to understand a fairly un-developed research are, e.g., the combination of resilience and sustainability. Furthermore, the study was not based on specific cases of supply chains but on professionals' view on the phenomena of supply chain resilience and sustainability in combination. The methods chosen for the three studies are discussed in the following sections in terms of data collection, sampling, and data analysis.

3.3.1 Study 1: Multiple-case study

The purpose of Study 1 was to identify logistical flows and tradeoffs able to enhance circularity by slowing the flows of materials and resources in PBS supply chains. The study followed a qualitative approach and a multiple-case study design (Yin, 2013) in order to gather rich data on circular activities and the actors, activities, flows, requirements, and tradeoffs involved. Due to the explorative nature of the research conducted for this thesis, the study began with a literature review to create the semi structured interview guide. As detailed in Table 2, the study was based on a purposive sample (Emmel, 2013) of 13 case products produced by global manufacturers with presence in Sweden. The firms sampled needed to be mature manufacturing companies, with a stated intent to explore the potential of services past initial sales and introduce circular initiatives into their business models. Moreover, the firms needed to have an end-to-end perspective on their products and rely upon PBS supply chains. Selecting larger, more established companies as firms made sense in the study because smaller companies are rarely developed in light of their PBS supply chains, and the study wanted to capture established PBS supply chains. Because each PBS supply chain depends on the actors and products involved, focusing on only one product was deemed insufficient to drawing more general conclusions on PBS supply chains. Thus, following Eisenhardt and Graebner's (2007) reasoning, rich empirical data regarding the phenomenon were collected using semi structured interviews in several cases. The products were chosen for having either a technical or hazardous component or material and needed to be available for purchase directly, by lease, or with a service contract. In line with purposive sampling (Emmel, 2013), the interviewees in the manufacturing companies were primarily chosen based on their competence with aftermarket services and support, supply chain management, logistics, and sustainability-oriented activities. The interviewees needed to have broad knowledge on PBS supply chains and offerings and represent a specific product in the supply chain. Variety in their roles was also targeted.

Table 2. Case products and the roles of interviewees at their companies in Study 1

Product	Role	Duration
Smart diaper with embedded silver thread (sensor) and mounted sensor and transmitter	Global director of intelligent solutions	78 min
Smart diaper with portable sensor	Global director of intelligent solutions	78 min
Plastic or metallic paper dispenser	Business development manager	64 min
Smart towel dispenser	Global brand services director	59 min
Smart office space with sensors	Product owner	63 min
Forklift	Purchasing manager and service manager	45 min
Autonomous lawnmower	Global aftermarket manager	75 min
Riding lawnmower	Global aftermarket manager	45 min
Chainsaw	Global aftermarket manager	48 min
Spotlight	Aftermarket and after-sales manager	56 min
Self-checkout kiosk	Aftermarket and after-sales manager	50 min
Entry and exit gate in store	Aftermarket and after-sales manager	64 min
Trucks	Aftermarket manager	91 min

Data collection in Study 1 entailed semi structured interviews with personnel in charge of the PBSs for a specific product. The interview guide (Miles & Huberman, 1994) aimed to encourage the interviewees to speak openly about the PBS supply chain (Bell & Bryman, 2018) yet remain within the area of interest to the study. Derived from the review of literature concerning the relationship between PBS and circularity, the guide was designed to gain insight into which services to continue investigating in the cases and what components of the supply chain should receive focus. The guide also provided an opportunity to discuss future ideas and solutions not already established in models in the companies but that showed potential for the future. The interviews were conducted face-to-face on-site at each company, recorded with prior permission of the interviewees, and transcribed by the other researchers and me. In addition, the interviewees furnished secondary data in the form of company documents, internal and external presentations, and company announcements. Data analysis followed an abductive approach between cases based on theoretical codes from the literature, a priori codes, and additional inductive codes that emerged during the analysis of the empirical data. Last, the data were summarized into codes describing the logistical flows and further analyzed to determine logistical tradeoffs.

3.3.2 Study 2: Multiple-case study

Study 2 investigated how PBS supply chains have been disrupted during the COVID-19 pandemic and how manufacturing firms have responded to those disruptions, all with the aim of developing a conceptual framework of transilience (Craighead *et al.,* 2020) in PBS supply chains. Given the emerging nature of the pandemic and the unexplored research topic of risk and resilience in PBS supply chains,

an explorative qualitative research design was followed to discover the distinct dimensions of disruptions amid the pandemic and to explore the new dimension of transilience. The research design was built upon the framework for thematic analysis developed by Boyatzis (1998), from which a framework of coding and analysis was developed. The study involved data collection in two steps: a multiple-case study and a secondary data search of 107 companies in Sweden. The multiple-case study entailed six large manufacturing firms (Table 3) with extensive experience with established PBS offerings. Sampling also considered the heterogeneity of interviewees (Robinson, 2014) such that they would collectively contribute different perspectives on the same industry sector and product. The interviewees were also chosen based on their knowledge in one or more fields of supply chain management, operations management, production, and sales and/or service management, and multiple interviewees were selected per case company.

Table 3. Case companies in Study 2

Case company	**Role**	**Duration**
Company 1: Truck manufacturer *(Repair, maintenance, uptime, refurbishment, and remanufacturing)*	Aftermarket manager for Europe	38 min
	Industrial supply chain analytics expert	40 min
	Inbound operations support manager	32 min
	Indirect purchaser of products and services manager	28 min
Company 2: Facilities management *(Repair)*	Group innovation manager	27 min
	Sales and service manager	26 min
Company 3: Forklift manufacturer *(Repair, maintenance, uptime, refurbishment, and remanufacturing)*	Vice president of manufacturing	30 min
	Production director	31 min
	Supply chain director	31 min
	Spare parts sales support manager	30 min
Company 4: Forklift manufacturer *(Repair, maintenance, uptime, refurbishment, and remanufacturing)*	Purchasing department manager	32 min
	Professional services manager	36 min
Company 5: Machinery manufacturer *(Repair, maintenance, and uptime)*	Vice president of sales and services	25 min
	Vice president of sourcing	30 min
	Supply and demand planning manager	36 min
Company 6: Health care equipment manufacturer *(Repair, maintenance, and uptime)*	President of global operational services and CIO	26 min
	Director of business support and ecommerce	36 min
	Vice president of global supply chain	33 min
	Vice president of global sourcing	35 min

The secondary data were based on journal articles, newspapers, online articles, internal company documents, and annual reports regarding 107 large and midsized companies. Those data were coded within the same framework as the interviews in order to validate and further develop the data. Furthermore, to strengthen the validity of the research addressing such an unexplored topic, the findings

were reinforced in a workshop with senior managers. The data were subsequently analyzed in a cross-case, inductive fashion following Boyatzis's (1998) procedure for thematic analysis. The empirical data, used as a basis to develop codes due to the unexplored nature of the topic, were structured and coded in NVivo. The discontinuities were grouped and linked with ways of coping with the pandemic directly from the firms that had used them and interpreted with reference to literature on supply chain resilience and services in order to clarify transilience in PBS supply chains.

3.3.3 Study 3: Interview study

The purpose of Study 3 was to explore synergies, tradeoffs, and priorities related to resilience and sustainability in manufacturing supply chains as a means to conceptualize the intersection of those concepts and mechanisms of their fragmentation. The study followed two RQs—namely, what are the key features of the intersection between resilience and sustainability in manufacturing supply chains, and what challenges hamper the alignment of resilience and sustainability in manufacturing supply chains? Because the discussion on combining sustainability science and resilience theory remains in its infancy (Fahimnia & Jabbarzadeh, 2016) and because the literature shows that those two topics have been studied independently (Redman, 2014), Study 3 followed an explorative qualitative research design (Miles et al., 2020) based on an interview study of industry representatives and a literature review conducted following a screening of papers addressing sustainability, resilience, and supply chains. The interview study involved the convenience sampling (Astroth & Chung, 2018) of supply chain professionals engaged in sustainability and/or resilience, whose details appear in Table 4.

Table 4. Interviewees in Study 3

Company	Role	Duration
Industrial equipment manufacturer	Purchasing manager	35 min
Food and beverage manufacturer	Supply chain planner	28 min
Retail manufacturer	Sustainability manager of global expansion	30 min
Truck manufacturer	Sourcing manager	42 min
Industrial robotics manufacturer	Global supply manager	45 min
Tools and accessories manufacturer	Supply chain project manager	45 min
Truck manufacturer	Senior excellence manager	40 min
Truck manufacturer	Head of sustainability	46 min

The literature search resulted in 274 papers relevant to the field that were reduced to 30 papers explicitly addressing both resilience and sustainability. The interviews were conducted online via Zoom or Microsoft Teams due to the pandemic, and the data were coded based on the literature in a process in which supply chain efforts and their impacts on resilience and sustainability were determined. Those findings were subsequently used to establish intersections between the literature and the empirical data as well as mechanisms of their fragmentation to align the two concepts in supply chains.

3.3.4 Data analysis to answer the RQs

Data analysis followed an abductive reasoning approach, which is a combination of a deductive approach and an inductive approach (Hurley *et al.,* 2021). The approach was suitable for the research conducted for the thesis because empirical and theoretical data have significant value, and the approach primarily takes its starting point in one of those types of data (Bell & Bryman, 2018). According to the approach, because neither theory nor empirical data can be understood or stand alone, researchers can broaden their perspectives and improve their understanding of both theoretical and empirical phenomena by iteratively investigating both types of data (Dubois & Gadde, 2014). Furthermore, abductive research approaches allow the continuous modification of the original framework (Dubois & Gadde, 2014), as is preferred for underdeveloped research topics such as the combination of PBS supply chains, circularity, sustainability, and resilience, as well as corresponds to the chosen research design (Maxwell, 2012b). Beyond that, because the research could not consider all possible solutions, iteratively analyzing empirical and theoretical findings made it easier to draw reliable conclusions (Kovács & Spens, 2005). Last, because the scope of the research changed based on empirical findings and the changing world, an abductive approach was considered to be ideal (Maxwell, 2012b).

3.4 Research quality

To maintain a high level of accuracy and quality throughout the research, the validity, reliability, and relevance of the collected data were evaluated via a carefully constructed research design. Triangulation was also achieved by using different sources and methods to investigate the same topic, which consequently enriched and confirmed the information and increased its validity and reliability (Yin, 2013). Data triangulation was accomplished by using literature reviews, interviewing multiple respondents from different companies, and employing secondary sources of data. The literature reviews functioned as a means to not only achieve an overview of PBS supply chains, circularity, resilience, and sustainability but also inform the three papers included in the thesis. The literature provided grounding in terms of the theoretical foundation, background, and framework for the thesis. Moreover, the theoretical background in all papers served as input to the interview guides used in empirical data collection, and that consideration ensured the high relevance of the interview questions. Although secondary data are somewhat limited by being more subjective in nature, consultancy reports were analyzed to recognize trends. Secondary data from the interviewees were also included because they came from reliable sources.

Although research quality is usually judged based on quantitative measurements, qualitative research has increasingly been published. Yin's (2013) proposed method of judging case studies is commonly used and includes four dimensions: construct validity, internal validity, external validity, and reliability. However, authors such as Miles *et al.* (2020) and Halldórsson and Aastrup (2003) have argued that those measurements are primarily appropriate for quantitative data. Because the research conducted for this

thesis was qualitative and referred primarily to supply chain management, Halldórsson and Aastrup (2003) have suggested adapting those four dimensions into four new ones that are more appropriate for qualitative research on supply chains: transferability, dependability, confirmability, and credibility, which together form a value of trustworthiness. Those four dimensions served as a basis for evaluating the quality of the research in this thesis because they view research on PBS supply chains as being multi-paradigmatic within logistics and supply chain management and consider such research's softer side (Halldórsson & Aastrup, 2003), see Table 5.

Table 5. Procedure for assessing research quality employed in the thesis

Criterion	Explanation	Application	Phase in case study
Transferability	General applicability of findings	Predefined questions in interview protocol based on relevant literature	Research design
		Cross-case analysis	Data analysis
		Presentation at workshops and conferences	Data analysis
		Interviews with multiple respondents	Data collection
		Emphasis on the contexts of the cases	Data analysis
		Specific procedure for coding and analysis in each paper	Data analysis
		Comparison of findings with evidence in the literature	Data analysis
		Use of replication logic in case studies	Research design
Dependability	Replicability of the study or trackability of methodological decisions	Having multiple researchers involved in all papers	Data collection
		Predefined questions in interview protocol based on relevant literature	Research design
		Data from interviews recorded and transcribed	Data collection
		Documentation of research progress in terms of research purpose, questions, methods, and decisions	Research design
		Documentation of data analysis	Data analysis
		Discussion of decisions with other researchers	Research design
		Peer review and examination of results	Data analysis
Conformability	Degree to which the research corresponds to its stated intent	Peer review and examination of results	Data analysis
		Review of findings by participants	Data collection
		Division of work and collaboration of researchers	Research design
		Comparison of data with evidence in the literature	Data analysis
		Use of multiple sources of evidence	Data collection
		Key informants' review of drafted case study reports	Data collection
Credibility	Degree to which reality is treated as a subjective construct	Assurance of the internal coherence of findings and concepts	Data analysis
		Repeat interviews with several respondents from both the same and different organizations	Data collection
		Validation of data with theory	Data analysis
		Discussion of results with respondents	Data analysis
		Triangulation and validation of data with other data sources	Data analysis
		Having researchers understand and avoid their own biases	Data analysis
		Peer review	Data analysis

Transferability refers to the applicability of findings beyond the specific context studied. Because the PBS supply chain is unique for each constellation of actors, the research's transferability was paramount. Transferability can be improved by cross-checking methods with interviewees, co-researchers, and peers and by following specific procedures in analyzing the data. By contrast, *dependability* refers to the possibility of replicating the study, which is generally difficult in qualitative research. For dependability, the goal is to provide richness of detail as a means to ensure that the methods can be followed (da Mota Pedrosa *et al.,* 2012; Halldórsson & Aastrup, 2003). Next, *conformability* refers to how well the research is free from biases. Conformability can be ensured by cross-checking the results and data with the current body of knowledge as well as with peers. Last, *credibility* refers to the degree to which researchers demonstrate their understanding that each interviewee influences their responses based on how they understand the world. To ensure credibility, several respondents should be used to access the same phenomenon, and multiple sources of data for data collection are preferable. Those four dimensions served as a basis to achieve research quality in the thesis, as further evaluated in Table 5.

Maxwell (2012b) has stressed the importance of critically examining literature while bearing in mind the purpose of the publication. Likewise, the selection of literature for the research was based on Eriksson and Wiedersheim-Paul's (2008) framework to ensure the accuracy of the literature review, as detailed in Table 6.

Table 6. Source criticism

Criteria	Explanation	Application in the research
Contemporary requirements	Even though the information was true at the point it was written, the information may not be valid today.	Use of up-to-date resources and assurance of authenticity by using multiple sources
Tendency criticism	Tendencies from the researcher can be found in the choice of words or facts presented.	Sources with different tendencies used to best extent
Dependency criticism	Two sources based on the same original source should not be accounted for in the study.	Use of original sources whenever possible
Authenticity	Authenticity can concern both the accuracy and source of the information.	Use of multiple sources

3.5 Research process

The research process undertaken during the first half of my doctoral work, similar to the studies included in this thesis, was exploratory and phenomenon-driven instead of positivistic and linear. Before the start of my work in April 2019, I was active in the manufacturing industry as a global feature leader of logistics services at Volvo Group Trucks Technology. Prior to that, I finished the Exponential Talent Trainee Program at Ericsson, which I began in June 2016 immediately after graduating from Chalmers University with a master's of science degree in mechanical engineering and a master's in supply chain management with an exchange year at École Nationale Supérieur des Arts et Métiers ParisTech in Paris,

France. My studies in mechanical and industrial engineering and management provided outstanding opportunities to study the two worlds of business and engineering and, more specifically, to become comfortable at the often challenging intersection of those two worlds. From my experience in the industry, I also witnessed tendencies of operating primarily in silos, and I hope that my background and future research can contribute to dismantling those silos.

When I started my doctoral work at Chalmers University, the general scope of my research was vague: to explore service management in the context of supply chain management. Following several meetings with my supervisor, Dr. Árni Halldórsson, to establish limitations of the research project, I decided to pursue the notion of circularity, which I have stayed true to, and how services that support products can contribute to circularity. Moreover, given my keen interest in supply chain management and service management, I ended up studying PBS supply chains and investigated the topic in considerable depth, as demonstrated in Paper 1. The topic fascinated me, and as the COVID-19 pandemic descended, we wasted no time in seeking to understand how the global crisis had affected and would affect PBSs and how companies could develop resilience in response. After finalizing Paper 2, my fellow researchers and I realized that resilience has to be understood in combination with sustainability, hence Paper 3. Figure 7 presents an overview of the research process with a timeline of the studies conducted and the associated papers, the licentiate thesis, and various presentations.

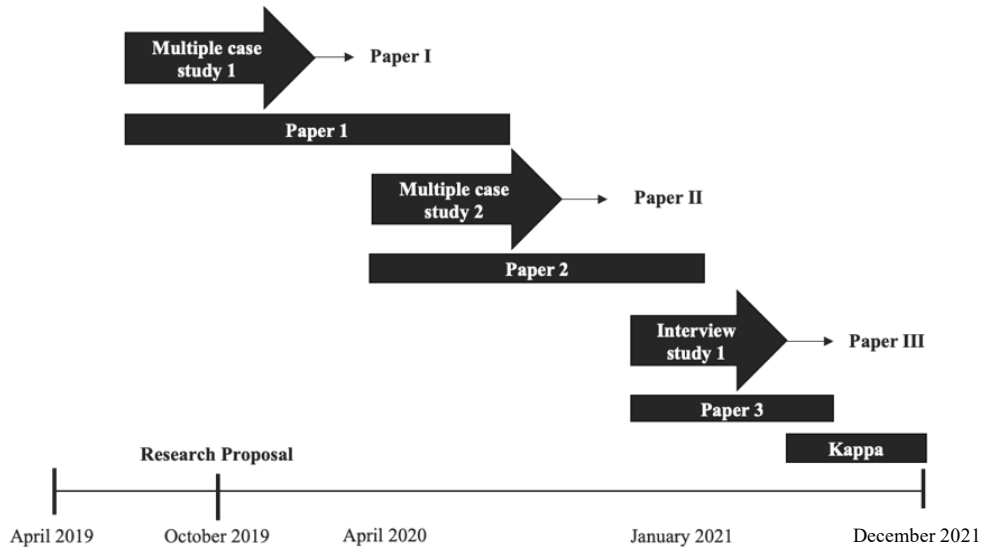

Figure 7. Timeline of the research process

4

Summary of the appended papers

It's not enough to be outstanding. You also need to stand out. – Erik Gatenholm

This chapter summarizes the three appended papers and outlines their key contributions in relation to the purpose of this research.

4.1 Paper 1

4.1.1 Background and purpose

An increased number of manufacturing firms have integrated circular approaches into their production and supply chains to replace the traditional linear "take, use, waste" economy. A circular economy, in which waste is eliminated and materials are used continuously, offers a possible solution to meet the increased scarcity of natural resources. One way to enhance circularity in supply chains is to introduce aftermarket services to support prolonged product lifetimes and thereby decelerate resource flows. However, aftermarket supply chains differ substantially from traditional supply chains in several ways. For one, the context of aftermarket supply chains is highly servitized and marked by increased attention to the service provider–customer relationship. Moreover, the point of sale is the starting point of the supply chain, and the customers, service providers, and parts suppliers are the focal actors. Variations in product lifetimes, disperse locations, and the quality of products during their in-use phase, as well as limited information sharing and transparency between the focal actors, provide further uncertainties in aftermarket supply chains. Although the flows of materials and information are important logistical flows in traditional supply chains, there is a lack of understanding of logistical flows in aftermarket supply chains and how they relate to each other. Against that background, Paper 1 investigates logistical flows and tradeoffs to support enhanced circularity in aftermarket supply chains.

4.1.2 Findings and contributions

Paper 1 takes aftermarket supply chains as its point of departure. My coauthors and I establish that PBSs that support the slowing of resource flows can be achieved by implementing three aftermarket services: repair and maintenance, reuse and redistribution, and refurbishment and remanufacturing. Those services can be further subdivided into 10 unique aftermarket supply chains. Using those 10 archetypes as a basis, the paper identifies a new dimension of the supply chain context—namely, flows of people and knowledge—to the established, conventional flows of material and information. People are essential in that context because a service often requires interaction or interface with a person, and the knowledge that the person possesses is vital to performing the service. Those two flows can therefore be regarded as fundamental in aftermarket supply chains. At the same time, those flows impose new requirements on supply chains whose realities are not accommodated by existing models and theories. By borrowing perspectives on tradeoffs from the literature and developing them based on our empirical findings, Paper 1 applies an old model to a new setting and, in turn, demonstrates that the model needs upgrading to capture new logistical flows and tradeoffs. In that way, the paper reaffirms the model's utility and the applicability of existing tools to a new context.

Two aspects of Paper 1 are especially responsible for its novel insights. First, the paper questions the conception of time as being positively associated with speed and, in turn, responsiveness, rapid delivery, and just-in-time delivery. Instead, we argue that deceleration is a condition favorable to enhancing circularity and the sustainable performance of a product across its life cycle. The second is the paper's consideration of the emerging context of aftermarket service supply chains, in which product and services related to them form integrated offerings. Those two aspects of Paper 1 set the foundation for its major theoretical and managerial contributions.

Paper 1's contribution of two new dimensions—flows of people and knowledge—to traditional information and material flows sheds light on a new tradeoff. Therein, material is given further depth by including people as a major resource needed to perform services, while information is given further depth by including knowledge, which may allow eliminating flows of people, parts, and/or products. With that contribution, professionals engaged in the development of aftermarket service offerings can identify people and knowledge as distinct features while planning their supply chains. Knowledge-intensive aftermarket services are recommended to reduce the transportation of parts, products, and/or people, which aligns what has been suggested due to the COVID-19 pandemic, during which remote or partly remote services have been used to improve resilience and sustainability.

4.2 Paper 2

4.2.1 Background and purpose

In affecting supply chains worldwide, the COVID-19 pandemic has cast doubt on the current logic of efficient, interlinked, global supply chains. Recent literature has focused on resilience and risk in precedent disruptions, ones initiated by shocks with rippling effects, which are typically limited to a region or sector and impact supply and/or demand. Although that literature predominantly focuses on the forward-facing traditional supply chain, focus has increasingly shifted toward service-based offerings, circularity, and, in turn, PBSs and product–service systems. Against that background, Paper 2 investigates how those particular PBS supply chains were affected and responded during the first 6 months of the COVID-19 pandemic. Because the circumstances created by the pandemic are unprecedented, there is theoretical and managerial interest in understanding and learning from the crisis. Along those lines, Paper 2 investigates how manufacturing firms have been impacted by discontinuities in their PBS supply chains due to the pandemic and analyzes initial responses during the initial months. We argue that the pandemic's severity calls for a response targeting more than resilience from manufacturing firms—in a word, *transilience*, defined as the ability to quickly restore some processes while at once radically changing others.

4.2.2 Findings and contributions

In rapidly transforming the world as we knew it, the COVID-19 pandemic has provided an excellent opportunity for researchers to study how companies can incorporate resilience into their supply chains. Using the pandemic as its context, Paper 2 provides a conceptual framework for transilience based on discontinuities and initial responses in PBS supply chains. The framework builds on the combination of characteristics of discontinuities that can be managed or unmanaged as well as three modes or responses, ranging from the restorative to the radical. In that way, the paper extends the traditional view on disruptions in supply chains to PBS supply chains by using the COVID-19 pandemic as a case.

Overall, Paper 2 argues that discontinuities affect suppliers and customers alike, for both the supply and demands sides of supply chains are affected. Although much of the impact and response relate to external factors, outside the firm's boundaries most measures are internally focused on returning the organization to working order. Thus, the literature focused on external measures to improve resilience needs to be complemented by immediate actions made within organizations. In that vein, Paper 2 introduces the dimension of manageability, supported by measures that can be taken to reduce unmanaged intervals during crises. Moreover, it articulates how those measures can cause deliberate or forced discontinuities. Last, the paper provide three modes of responding to those discontinuities and striving for transilience adopted by relatively transilient PBS supply chains: Mode 1 (i.e., extending the norm but up- or downscaling PBS delivery), Mode 2 (i.e., extending the norm but adding or improving PBS offerings), and Mode 3 (i.e., embracing a new norm with radical changes in new PBS offerings). These modes are all related to the panarchy theory in the third stage of release to grasp an opportunity to change towards a new normal.

The findings presented in Paper 2 contribute to theory by integrating PBS supply chain discontinuities into the domain of service supply chains. The paper provides an initial analysis of how transilience can operate in PBS supply chains and sharpen attention to risk and resilience in the literature on services. Moreover, in the supply chain domain, the paper expands the supply–demand view to include organizational and interactional discontinuities and, in that context, underscores the idea of manageable and unmanageable discontinuities: the former being either deliberate or forced, the latter referring to external discontinuities on the supply and demand sides. The paper ultimately argues that providers of PBS offerings need to strive for transilience in their supply chains and provides a useful framework that can be used as a guiding tool.

4.3 Paper 3

4.3.1 Background and purpose

The COVID-19 pandemic has spurred companies to rearrange their businesses in order to increase their resilience. However, those efforts have not always contributed to sustainable development. Supply chains after the pandemic will require organizations to fundamentally rethink their strategies for supply chain resilience and at once align them with their own sustainable development. In so doing, a key challenge is to understand the core nature of sustainability and resilience, how they can be combined, and what level of resilience to strive for. In that context, sustainability and resilience are multidimensional and correlated in myriad different ways; they operate at different paces and levels, such that *resilience* mostly refers to short-term adaptive changes and *sustainability* to more long-term targets. Likewise, the literature is usually either focused on either sustainability or resilience, while the intersection between the two remains unclear. In response, Paper 3 explores that intersection both in the literature and in empirical findings to answer two RQs: What are the key features of the intersection between resilience and sustainability in manufacturing supply chains, and what challenges hamper the alignment of resilience and sustainability in manufacturing supply chains?

4.3.2 Findings and contributions

Paper 3 presents a conceptualization of the intersection between resilience and sustainability in supply chains based on a literature review and interview study. The analysis provides two primary contributions: intersections between resilience and sustainability and mechanisms of fragmentation that prevent the alignment of those concepts. Briefly put, the literature as well as empirical findings indicate a dominant focus on resilience, as well as an overriding emphasis on financial aspects over social and environmental sustainability, synergies, tensions, and temporal aspects, such that sustainability operates along a longer time horizon in general, usually with technology as an enabler. Despite the convergence and proven importance for integrating resilience and sustainability in the supply chain, they are fragmented with regard to real-world practice. In that light, the paper provides three mechanisms that contribute to such fragmentation: an organizational separation between resilience and sustainability, tensions between the two (e.g., improved redundancy does not necessarily contribute to environmental sustainability), organization separation between where resilience and sustainability are handled in different department and by different people, and temporal asymmetry that complicates alignment. In sum, the paper contributes to knowledge in the supply chain management literature by providing an overview of intersections and mechanisms of fragmentation between resilience and sustainability. Moreover, it guide practitioners in understanding the nature of those mechanisms in their efforts to align concepts in their supply chains.

5

Discussion

Do not go where the path may lead, go instead where there is no path and leave a trail. – Ralph Waldo Emerson

This chapter provides answers to the two RQs (i.e., "How do logistical tradeoffs enhance resilience in PBS supply chains?" and "What new building blocks of resilience are required in PBS supply chains?) in order to achieve the thesis's purpose of elucidating the relationship between circularity and resilience and of providing guidance for realizing resilient PBS supply chains. The analysis is based on the results presented in the three appended papers and on the thesis's frame of reference.

5.1 Overview

In summary, this thesis has three main findings. First, regarding the relationship between circularity and resilience and in response to RQ1, the thesis highlights that PBS supply chains must be understood from a wider perspective on logistical tradeoffs—that is, material versus people, people versus knowledge, and knowledge versus information—or what is commonly referred to as the "product-based logistical tradeoff" in supply chains between material and information. Those tradeoffs are essential when designing PBS supply chains and corresponding PBS offerings in line with transitioning to enhanced circularity. In this thesis, the relationship between circularity and resilience is operationalized according to those tradeoffs and their ability to respond to disruptions and foster resilience. The findings highlight the importance of improved local knowledge that is close to consumers and decreased dependencies on tangible flows. That finding matters, for adjusting those tradeoffs can enhance circularity and provide potential for developing resilience.

Second, regarding guidance for resilient PBS supply chains and in response to RQ2, the thesis provides a conceptual framework consisting of building blocks toward resilience in PBS supply chains. In combination with sustainability, the framework includes adaptive and transformative dimensions of resilience, operationalized in three modes of resilience. Meanwhile, the framework emphasizes sustainability achieved by two enablers: implementing technology and changing consumers' behavior. The framework is an important contribution, one that can provide guidance for both researchers and practitioners as they continue to pursue resilience in PBS supply chains during and after the COVID-19 pandemic. These three findings are further elaborated in chapter 5.2 and 5.3 hereunder.

5.2 The ability of logistical tradeoffs to respond to disruptions

In the context of circularity, resilience largely pertains to sustaining optimized cycles in which products are designed for longevity and optimized for disassembly and reuse (Ibn-Mohammed *et al.,* 2020). However, the task of designing products and supply chains to support circularity and resilience necessarily confronts numerous challenges (Bocken *et al.,* 2016). In that context, this thesis contributes valuable insights into how circularity, operationalized as logistical tradeoffs, facilitate resilience in PBS supply chains. To clarify that relationship between circularity and resilience, as addressed in the first part of the thesis's purpose, this section first addresses the logistical tradeoffs involved. Second, it describes the disruptions observed during the COVID-19 pandemic, followed by an analysis on how they relate to PBS settings. Last, the ability of the logistical tradeoffs to respond to those disruptions are scrutinized.

5.2.1 Logistical tradeoffs in PBS supply chains

The industrial economy has long rested on the traditional linear economic system of taking resources, making products from them, and disposing of the products at the end of their lives (Ibn-Mohammed *et al.,* 2020). On the contrary, PBSs support the deceleration of resource flows, which contributes to enhanced circularity and, in turn, both environmental and financial benefits (Bocken *et al.,* 2016). However, in the process, PBS settings introduce new uncertainties into supply chains due to their differences with traditional product-based supply chains (Gatenholm *et al.,* 2021). The transition to circularity thus entails new variations, as presented in Chapter 2, in terms of the volume, location, quality, and lifetime of products, as well as the knowledge, priorities, and information of actors involved. Furthermore, because PBS supply chains involve people and knowledge as two important dimensions (Gatenholm *et al.,* 2021), the product-based logistical tradeoff between material and information (Christopher, 2016; Spekman & Davis, 2004) is therefore complemented with tradeoffs between knowledge and people as important resources in PBS supply chains able to handle variation related to the transition to circularity and PBS offerings (Gatenholm *et al.,* 2021), as shown in Figure 8.

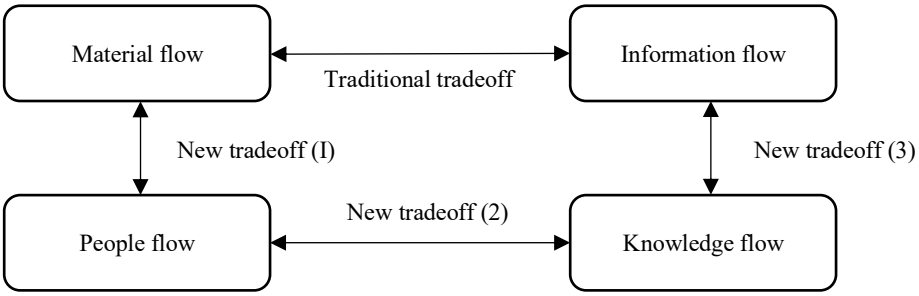

Figure 8. Tradeoffs in product-based service supply chains

Those new tradeoffs are important in PBS supply chains because they operate as means to handle variation when engaging in circularity. The dimensions of people and knowledge emphasize locally situated individuals who can perform service operations; thus, knowledge exchange between service providers and local resources can increase local knowledge and decrease the need for people to move products (i.e., material) between providers (Gebauer *et al.,* 2013). Similarly, moving people to products can eliminate the need to move the products themselves. Last, a tradeoff exists between information and knowledge, such that a local resource with a high degree of knowledge or a product with smart technology diminishes the information required by service producers. Thus, customers, or even products, can meet their own needs for PBSs on the customers' premises without significant involvement from service providers. As Del Giudice *et al.* (2021) have also argued, smart products can automatically draw conclusions based on their data, which can also reduce the need for information. In sum, increased local knowledge and/or information decreases dependencies on tangible flows and the formerly mentioned uncertainties related to transitioning to a circular economy.

5.2.2 Disruptions in PBS supply chains

Literature on risks in PBS supply chains is scarce (Ostrom *et al.,* 2021), while research on risks and resilience in supply chains has primarily focused on product-centric settings (Pettit *et al.,* 2019). PBS supply chains, however, involve the flows of not only physical products and spare parts but also resources in terms of people, information, and knowledge during the in-use phase of products (Gatenholm *et al.,* 2021). Thus, several new dimensions concerning disruptions arise in that service-based context that contribute to additional uncertainties. Understanding the ability of the presented logistical tradeoffs to cultivate resilience first requires outlining those disruptions and understanding how they relate to PBS supply chains. Figure 9, based on archetypes of PBS supply chains, depict the type of logistical flows that occur between each actor in the supply chain (Gatenholm *et al.,* 2021). The uncertainties, reported in Paper 2, are separated into four categories: organizational disruptions, supply side disruptions, service demand-side disruptions, and interactional disruptions.

Starting with the supply side between parts suppliers and OEMs or service providers, only the flows of information and parts are present, hence the lack of new circularity-specific logistical tradeoffs in the setting. Likewise, because organizational disruptions affect only OEMs or service providers, logistical tradeoffs are absent as well. Thus, in those two product-based settings, the logistical tradeoffs presented in Figure 8 are irrelevant, for neither knowledge nor people are involved in the operation. Moreover, the logistical tradeoffs are developed with the notion of a service operation, and thus not applicable to reuse and redistribution (Gatenholm *et al.,* 2021). Customer B in Figure 9 was therefore excluded from further analysis.

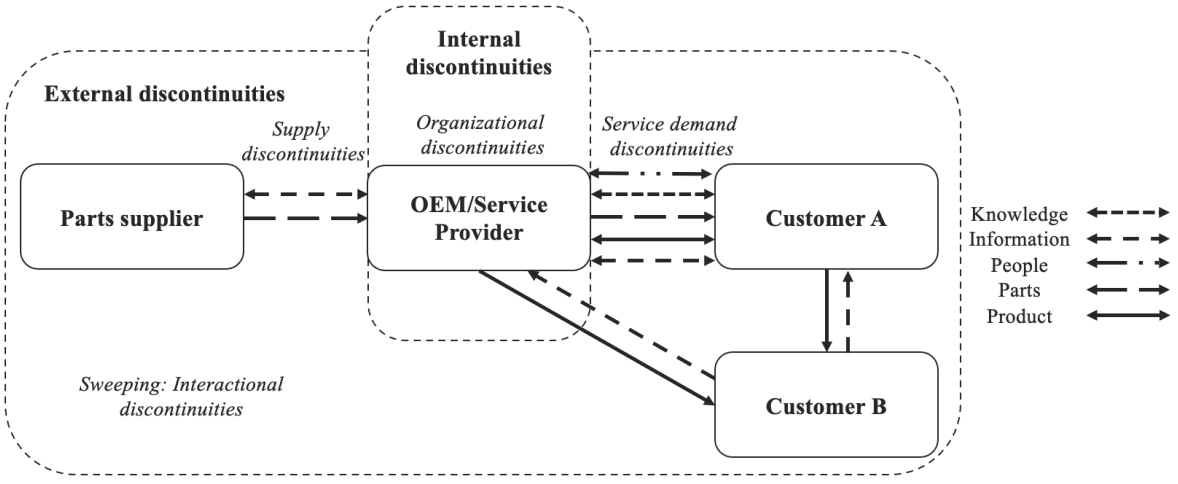

Figure 9. Logistical flows and disruptions in product-based service supply chains

However, the service-based dimension of PBSs is strictly associated with logistical tradeoffs. Therein, some new dimensions are present that confirm Cortez and Johnston's (2018) notion that the severity of major external disruptions relate to both suppliers and customers in conjunction. Paper 2 highlights that customer-related disruptions on the service-demand side range from fluctuations in service demand due

to changes in product usage to more severe developments that can either increase demand for critical services or effect total market shutdowns. Thus, disruptions in PBS supply chains reflect key features of service supply chains identified as being bidirectional—for example, the supply and demand sides being similarly affected (Sampson & Spring, 2012). Moreover, another new dimension relates to limitations on physical interaction, which severely impact the service personnel's ability to cater to needs for service. Thus, to understand the ability of logistical tradeoffs to cultivate resilience, this thesis emphasizes disruptions for the service demand side and organizational disruptions as new dimensions of uncertainties in PBS supply chains.

5.2.3 Responding to disruptions in PBS supply chains

Extending current understandings of resilience in PBS supply chains in light of the dimensions of tradeoffs shows that the dimensions of knowledge and information are crucial to handling variation, from the perspective of handling uncertainties related to circularity and to handling volatile settings. Grounded in a focus on the customer–provider dyad, the PBS setting, and the literature on resilience, Figure 10 illustrates the logistical tradeoffs' ability to enhance resilience in PBS supply chains.

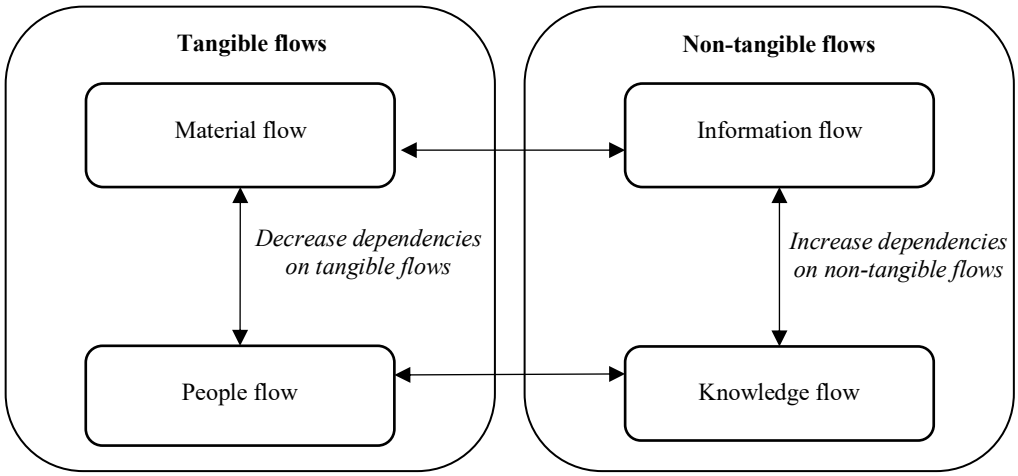

Figure 10. Tradeoffs for building resilience

To increase the exchange of information and knowledge between customers, service providers, and suppliers, increased collaboration is essential. Added to Wieland and Wallenburg's (2013) finding that collaboration and increased cooperation—conducting activities together for mutual gain and benefit—are associated with increased resilience, this thesis also highlights how joint activities are enforced by knowledge and information sharing and associated with increased circularity and resilience. In the analysis, joint relationships were treated in terms of both information sharing and knowledge sharing, which allowed deriving new fine-grained insights. That dynamic also aligns with the findings of Wieland and Wallenburg (2012) and Scholten and Schilder (2015), who have argued that collaborative relationships, alignment, and risk-sharing help supply chains to build up resilience in terms of flexibility,

visibility, and velocity. Ju *et al. (*2020) agree that knowledge sharing, and collaboration helps to foster resilience by improving the quality of integration. On the contrary, Wieland and Wallenburg (2013) have argued that integration does not play a role in building resilience. In line with resource dependency theory (Pfeffer & Salancik, 2003), they have maintained that dependency on those other constructs adds to uncertainties. This thesis disagrees with Wieland and Wallenburg (2013) but agrees with Ju *et al.* (2020) that knowledge and information sharing increase the quality of integration, which consequently increases the willingness of customers and providers to engage in joint solutions seeking mutual gain to increase velocity in responding to variations (Scholten & Schilder, 2015). During the COVID-19 pandemic, that dynamic was understood to mean that a high quality of integration prompted rapid responses that could secure service offerings and delivery to customers, as detailed in Paper 2.

Scholten and Schilder (2015) have found that mutual dependence between organizations in a supply chain increases the chain's resilience. Along those lines, this thesis shows that mutual dependence between an organization and its customers increases resilience. Actors that depend on one another tend to value mutual success and be more prone to sharing information and working together to solve problems and to develop products and services (Soosay *et al.,* 2008). A highly servitized setting, such as the PBS is, calls for better customer–provider relationships (Baines *et al.,* 2017; Neely *et al.,* 2011), in which risk can be shared among the actors involved (Reim *et al.,* 2015). As key players in PBS supply chains (Tran & Kummer, 2015), customers should be more involved, which can be empowered by increased knowledge and information sharing. Sampson and Spring (2012) have advocated the self-service of products as a means to improve product–service settings, which require a specific level of local knowledge and information sharing. Enhanced knowledge also provides the right skills for customers to prolong the lifetimes of products without the extensive involvement of providers, which can counter interactional disruptions that inhibit the physical involvement of providers. Performing services locally reduces or even eliminates the need for physical interactions, which during major disruptions may be restricted, as in the case of the COVID-19 pandemic (Craighead *et al.,* 2020).

5.2.4 Limitations of logistical tradeoffs' ability to develop resilience

Close information and knowledge sharing between service providers and customers is not always achievable, positive, wanted, or needed. First, the market or product might not be optimized for collaboration. According to de Leeuw and Fransoo (2009), the level of collaboration between supply chain actors is determined by the market (i.e., demand and supply uncertainty) and the product or service (i.e., criticality and the level of customization). That circumstance would facilitate a low level of information sharing as a collaborative measure and thus a low level of resilience. However, this thesis emphasizes knowledge sharing as an important measure of collaboration, and, based on the tradeoffs, the level of information can be low if the level of knowledge sharing is high. The more jointly created knowledge available that has been developed close to the product, the more inclined the customers are

to engaging in collaborative activities to solve their current predicaments (Gatenholm *et al.,* 2021). A low level of information sharing leads to a low level of visibility (Finkenstadt & Handfield, 2021). However, accumulating knowledge on how to perform services locally allows action during disruptions without the presence of service providers and thus improves velocity. Even so, that dynamic is not applicable to the flow of materials, for a low level of information sharing between service providers and customers with parts suppliers can entail an un-optimized flow of material.

Second, relationships may be difficult to cultivate in PBS supply chains given the large volume of small, private, unique customers involved (Gatenholm *et al.,* 2021). Long-term relationships are highlighted in the literature as having a strong correlation with good collaborations (Singh & Power, 2009). However, in PBS supply chains, those relationships may be difficult to develop, for there are typically many customers and, in turn, highly disperse locations of products and not enough resources or incentives for service providers to engage in close relationships with each customer (Gatenholm *et al.,* 2021; Hernandez *et al.,* 2018).

Third. organizations typically do not share information, which naturally delays the release of information into supply chains (Jüttner & Maklan, 2011). The lack of information reduces flexibility, which is an important aspect of resilience (Zhu *et al.,* 2018). Moreover, in line with the tradeoffs, the lack of information requires a higher degree of material flows, which increase the PBS supply chain's vulnerability. However, as argued before, a low level of information can be mitigated by a high degree of local knowledge.

Last, customers may hesitate to be involved in service offerings that they have paid for. Collaboration depends on situations that allow for mutual benefits (Scholten & Shilder, 2015), and although performing services locally increases the velocity and flexibility of service provision, the involvement of customers entails several issues that deserve attention. For instance, the responsibility for service quality is transferred from service providers to local resources, which could be the customers themselves and, in that case, pose obstacles for liability. They could also be local resources that are hired—for instance, janitors (Gatenholm *et al.,* 2021). In that case, contracts with clear responsibilities need to be in place between local resources and service providers.

5.3 Building blocks of resilience in PBS supply chains

Although this thesis has highlighted the ability of logistical tradeoffs to foster resilience, those tradeoffs alone cannot handle all external disruptions in PBS supply chains and relate only to some dimensions of disruptive events in PBS supply chains. As the frequency and impact of supply chain disruptions increase, resilient supply chains that can absorb such shocks are of great importance (Barcaccia *et al.,* 2020). In particular, the vulnerability of global supply chains has been critically exposed during the COVID-19 pandemic (Craighead *et al,.* 2020; Wieland, 2021; Ibn-Mohammed *et al.,* 2020; Nandi *et al,* 2021; Barcaccia *et al.,* 2020), and, in response, several authors have called for greater attention to the

adaptability and transformability of supply chains to adjust to new norms after such disruptive events (Adobor, 2020; Wieland & Durach, 2021; Wieland, 2021).

In line with the work of Craighead *et al.* (2020), this thesis builds upon the notion of transilience by incorporating adaptability and transformability in PBS supply chains, in line with the second part of the thesis's purpose, and offers guidance toward realizing resilient PBS supply chains. Transilience promotes restoring some processes while simultaneously transforming others (Craighead *et al.,* 2020) and not necessarily returning to an established state of equilibrium following a disruption but rather promoting functional existence via continuous transformation (Wieland, 2021). That view show the potential for conceptual convergence with PBS settings, which call for a high degree of adaptation and transformation to accommodate the ever-changing landscape of customers and the market (Gatenholm *et al.,* 2021). Because the need for sustainability has intensified during the COVID-19 pandemic, and because companies need to align their strategic objectives with the three dimensions of sustainability (Zavala-Alcívar *et al.,* 2020) while cultivating sustainability, this thesis broadens the definition of *transilience* as being solely adaptive and transformative to also include sustainability as a third dimension. That revision is in line with several ongoing initiatives (e.g., Industry 5.0, the EU's green deal, and the OECD's "building back better" initiative) that emphasize how neither resilience nor sustainability can survive alone. Incorporating those uncertainties and building blocks, Figure 11 provides the final framework of the thesis.

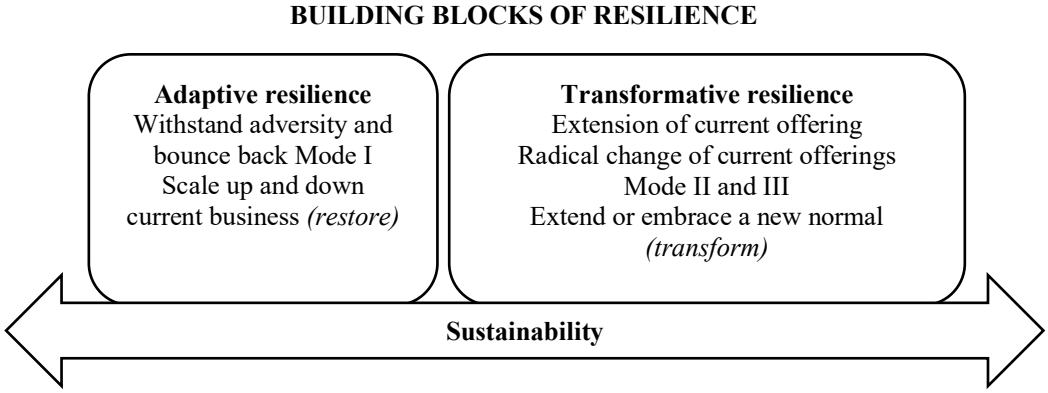

Figure 11. Conceptual framework of resilience in the PBS supply chain

Figure 11 presents the building blocks of resilience in PBS supply chains derived from the frame of reference and the findings in Papers 1–3. Therein, resilience is divided into adaptive and transformative resilience, which are further subdivided into three modes of resilience. Sustainability is presented as a core dimension spanning the entire process, while uncertainties are advanced to include dimensions from normal and volatile market settings. Those uncertainties are constraints of PBS supply chains that prescribe or control the need for resilience.

5.3.1 Adaptive and transformative resilience

The two concepts of adaptive and transformative resilience have hardly been studied in conjunction. Whereas adaptive resilience, here referred to as a supply chain's ability to recover from disruptions, is widely addressed in the literature on risk and resilience in supply chains, transformative resilience has remained underexamined, largely because the necessity of such thinking has not been as clear as it is now following the intense, long-standing shock of the COVID-19 pandemic (Wieland, 2021). However, because the shock has left supply chains in a state that is simply impossible to address with adaptive measures mentioned in the literature (Craighead *et al.,* 2020), it has presented various opportunities to progress instead of reverting to the status quo and, as described in resilience engineering (Hollnagel *et al.,* 2006), bounce forward through transformation. Of course, such actions do not occur of their own volition; each actor in a supply chain must recognize and seize the opportunity. To facilitate that process, Paper 2 presents three ways of realizing adaptive and transformative resilience, ranging from the purely restorative to the radical. All based on the notion of transilience (Craighead *et al.,* 2020), the three modes incorporate the capacity to both withstand and recover: Mode 1 (i.e., extending the norm but up- or downscaling PBS delivery), Mode 2 (i.e., extending the norm but adding or improving PBS offerings), and Mode 3 (i.e., embracing a new norm with radical changes in new PBS offerings).

Representing adaptive resilience, Mode 1 includes what is usually prescribed in the literature on risk and resilience in supply chains—for instance, ensuring the flexible production of products and services that can shift volumes without significant increases in cost (Dubey *et al.,* 2021), using multiple or dual sources, sharing risks with other actors (Manuj & Mentzer, 2008), creating redundancy with increased inventory levels in general and for critical parts in particular (Vanpoucke & Ellis, 2019), improving information sharing (Chopra & Sodhi, 2014) and collaboration (Azadegan & Dooley, 2021) in the supply chain, practicing flexibility with suppliers (Tang, 2006), and even maintaining redundant suppliers (Chopra & Sodhi, 2014). However, in PBS supply chains, the organizational efforts linked to service delivery are also included in Mode 1 because they promote scaling businesses up or down. Also included are actions such as allocating resources and enabling remote working options, as discussed in Paper 2. Those strategies are appropriate for smaller disruptions in traditional supply chains (Ali *et al.,* 2017; Craighead *et al.,* 2020) and may very well capture the supply-side and organizational disruptions of PBS supply chains, which, as in traditional supply chains, involve the flow of information and parts. However, for demand-side and interactional disruptions involving the flows of people and knowledge (Gatenholm *et al.,* 2021), those strategies may not be sufficient, for they may not be adapted to include those types of flows. Resilience in PBS supply chains has therefore been extended to include two new modes: capturing the transformative dimension of the demand side and interactional side of disruptions.

Representing transformative resilience are the other two modes: Mode 2 (i.e., extending the norm but adding or improving PBS offerings) and Mode 3 (i.e., Embracing a new norm with radical changes in

new PBS offerings). Both of those modes shift the focus of adaptive measures in PBS offerings by adapting them to new realities. As such, they uphold the idea of transformative resilience—that is, the ability to change or even radically change some processes (Craighead *et al.,* 2020). The service-based context of PBSs provides further evidence as to why those two modes are particularly important. The service offering and service delivery are intuitive (Vilko & Ritala, 2014), meaning that customers' involvement in the development of the service offering is crucial (Brax, 2005). Unlike tangible products, which generally do not physically change during major disruptions, services should be adapted to current situations based on customers' feedback (Reim *et al.,* 2015). Although statistical data about service disruptions are few and far between (Vilko & Ritala, 2014), services are doubtlessly unique to each situation because they involve human actors (Brax, 2005) and constitute real-time activities (Vilko & Ritala, 2014). Thus, for each of those unique situations, there should be a transformative element of resilience to adapt the service based on the specific situation and customer. As Åhlström and Nordin (2006) have proposed, because the relationship between the customer and service provider is vital, there must be an element of flexibility in terms of changing service offerings. Because PBS settings are highly dependent on users, PBS supply chains need to be able to quickly adapt to changed demand and behaviors (Gatenholm *et al.,* 2021). Examples of Mode 2 include adding a remote solution to maintenance and repair as well as allowing customers to leave products outside workshops in order to eliminate physical contact. During the COVID-19 pandemic, social distancing has forced companies, in conjunction with their customers, to quickly transform their services into ones that can replace longstanding practices. Some of those transformative changes may survive the pandemic. In that light, Mode 3 represents a system radically changed by an ongoing pandemic, meaning that additional empirical evidence of those transformations should be captured at a later stage.

5.3.2 The sustainable dimension of resilience

Even though sustainability was the chief focus of most industrial initiatives and innovations prior to the COVID-19 pandemic, research on both sustainability and resilience in supply chains has remained ambiguous and underdeveloped (Fahimnia *et al.,* 2019). Since the outbreak of the COVID-19 pandemic, those two concepts have needed to be regarded as equally vital for a firm's survival. Nevertheless, the capabilities required to jointly build resilience and sustainability in supply chains have remained unknown (Negri *et al.,* 2021). As reported in Paper 3, the same indications surfaced in the empirical data. None of the interviewees had considered the outcomes of their resilience strategies on sustainability, for their central focus had been recovery, with all sustainability-oriented actions taken before the crisis placed on hold. Although researchers have formed some consensus on the theoretical foundations of sustainability in supply chains, resilience in supply chains has no such consensus (Ibn-Mohammed *et al.,* 2020). Likewise, though both streams of research have long existed, research on sustainability has seen greater growth and matured to a greater extent than research on resilience. This

thesis presents an early attempt to integrate sustainability into the three modes of adaptive and transformative resilience. At the same time, because progress toward sustainability primarily takes the road of win–win opportunities, engagement in sustainability requires an economic incentive (Golini *et al.,* 2017). Sarkis *et al.* (2020) have even argued that implementing any strategies for resilience and/or sustainability requires an economic incentive, preferably in the short term.

Several authors (Carvalho *et al.,* 2011; Fahimnia & Jabbarzadeh, 2016; Govindan *et al.,* 2014; Jabbarzadeh et al., 2018; Mari *et al.,* 2016; Rajesh, 2018; Sarkis *et al.,* 2020; Zavala-Alcívar *et al.,* 2020) have addressed synergies and tensions between resilience and sustainability. Tensions, for example, include building redundancy, which promotes resilience, versus minimizing waste, which promotes environmental sustainability. The research's empirical findings presented in Paper 3 indicate the same tendencies, including for instance that dual sourcing and using green suppliers have an adverse impact on one or more dimensions of resilience and sustainability. Because resilience largely focuses on improving flexibility and redundancy, not efficiency (Caniato & Rice, 2003), improving resilience in terms of flexibility and redundancy contributes negatively to both the economic and environmental dimensions of sustainability. In addition, progress in sustainability, at least from an environmental and social perspective, is generally slow, and improvements for sustainability have to be exceptionally convincing for organizations to invest in them (Nikolaou *et al.,* 2019). By contrast, resilience is primarily a short-term strategy for risk mitigation and recovery (Christopher & Peck, 2004). Taken together, the objectives create an inevitable conflict of interest, in which a short-term priority of resilience inhibits long-term sustainable development, as elaborated in Paper 3. Thus, aligning the two in supply chains is a major challenge that both industry actors and researchers recognize and need to address (Sarkis *et al.,* 2020; Zavala-Alcívar *et al.,* 2020).

5.3.3 Potential enablers of building blocks of resilience in PBS supply chains

The resilience framework for PBS supply chains presented in this thesis is a first step toward integrating sustainability practices when cultivating resilience and distinguishing adaptive from transformative resilience. This thesis present two enablers for working with the building blocks of resilience in PBS supply chains. First, the digitalization of supply chains by leveraging disruptive digital technologies and tools, including the Internet of Things, artificial intelligence, cloud computing, and 3D printing, constitutes an important step toward decreasing dependencies on tangible resources, facilitating resilience, and improving sustainability-related performance (Raut *et al.,* 2021; Ibn-Mohammed *et al.,* 2020). Empirical data reported in Paper 3 also show that companies view digital technology as a major enabler of resilience and sustainability in their supply chains. Such digital technology not only allows gathering knowledge about a product's location, its condition, and the availability of assets (Ivanov & Dolgui, 2020b) but also enables improved communication between OEMs, customers, and parts suppliers. Thus, knowledge concerning the product can be used to draw conclusions based on the service

offering and delivery, which contributes to circularity, sustainability, and resilience. Another important step toward increased knowledge is predictive maintenance (Ibn-Mohammed *et al.,* 2020), which constitutes an ideal vehicle for enhanced circularity in PBS supply chains able to contribute to sustainability and resilience (Pagoropoulos *et al.,* 2017).

In all three modes, digital tools facilitate resilience. In Mode 1, they improve the planning of resources, and in Modes 2 and 3, they provide guidance for how service offerings and delivery can be developed to meet new demands among customers and in the market. All of those new technologies contribute to increased knowledge, which, based on the logistical tradeoffs, decrease dependencies on tangible flows. The result is a direct positive effect on resilience and sustainability.

Second, the COVID-19 pandemic has driven behavioral and market changes that have promoted circularity-oriented strategies and accelerated the transition to PBSs (Ibn-Mohammed *et al.,* 2020). Those changes in behavior can also facilitate resilience, sustainability, and competitiveness. In response to the pandemic, several communities have developed local markets (Sarkis *et al.,* 2020), while several PBS supply chains have developed local solutions to meet altered demands for services and in customers, as captured in Modes 2 and 3. A remote solution in which customers or locals were trained to perform services is one example. The necessity of remote solutions was highlighted by the requirement of social distancing (Dingel & Neiman, 2020), and the survival of one PBS supply chain largely depended on the ability of the OEM to adapt its service offerings and delivery for remote locations (Zaagsma *et al.,* 2020). Those trends mean less transportation, increased knowledge- and information-sharing, and, as a result, less waste and emissions due to cooperative initiatives (Gatenholm *et al.,* 2021).

Nevertheless, the questions remains whether a circular economy can help to build supply chain resilience. In this thesis, the tradeoffs supporting enhanced circularity have been shown to facilitate resilience, and those changes are expected to withstand as largely permanent solutions (Allan 2020). Even so, the application of such solutions was largely accepted by customers because the pandemic had eliminated all other options. The changed market and changes in customers' behavior were catalysts for sustainability, and companies that benefited from changes in their transformative resilience encouraged customers to continue with them during the COVID-19 pandemic. In the context of PBSs, the pandemic may have accelerated changes toward sustainable development instead of resulting in a negative rebound effect on environmental sustainability. In any case, the pandemic has emphasized the usefulness of transformative resilience in terms of extended services, as captured in Mode 2 and 3, instead of physical services and encouraged a shift toward servitization and circularity.

6

Conclusion

The time is always right to do what is right. – Martin Luther King, Jr.

This chapter presents the conclusion of the thesis and offers suggestions for future research. The purpose of the thesis has been to understand the relationship between circularity and resilience and to provide guidance on realizing resilient PBS supply chains. The research conducted for the thesis addressed that purpose by answering two RQs (i.e., "How do logistical tradeoffs enhance resilience in PBS supply chains?" and "What are the building blocks of resilience in PBS supply chains?") in three studies that resulted in three corresponding papers. This conclusion is separated into theoretical and managerial implications, followed by suggestions for future research.

6.1 Theoretical implications

RQ1 addressed the intersection between circularity and resilience, specifically the ability of logistical tradeoffs to foster resilience in PBS supply chains. In answering that question, this thesis makes two important contributions to the literature on supply chain management and service management in terms of designing service delivery and service offerings. First, the thesis highlights that PBS supply chains must be understood from a wider perspective on logistical tradeoffs (i.e., material versus people, people versus knowledge, and knowledge versus information) along with traditional logistical tradeoffs in product-based supply chains (i.e., material versus information). That finding is important for supply chain management when designing PBS supply chains and corresponding PBS offerings in line with transitioning to enhanced circularity. In designing service offerings, those new dimensions should be taken into consideration, along with added focus on solutions to improve local knowledge. Likewise, PBS supply chains should be designed such that knowledge can be enhanced locally and, in turn, tangible resource flows decelerated.

Second, the thesis highlights the intersection between circularity and resilience by clarifying the ability of the mentioned logistical tradeoffs to respond to disruptions (e.g., build resilience) in PBS supply chains. Whereas the first contribution relates to uncertainties during normal market situations, the second contribution relates to uncertainties during volatile ones. Thus, the finding is also important because strategically adjusting those tradeoffs has the potential to not only enhance circularity but also build resilience in the process. In sum, the findings highlight the importance of improved local knowledge developed closes to the consumers. For the literature on service, the finding is important for designing PBS offerings as well, in which local knowledge should be a parameter. Because local knowledge has a direct relationship with the flow of material and people, the finding additionally contributes to literature on supply chain management.

Those two contributions are an example of process style theorizing (Cornelissen et al., 2021) where complex, interdependent sequences of events which led to certain outcomes were captured. In this thesis's case, the complex, interdependent events are the PBS supply chain collectively, which involves new logistical tradeoffs and customers. The thesis underscores that utilizing customers and/or local resources as parts of service offerings and delivery leads to enhanced circularity and resilience in PBS supply chains. Moreover, in terms of the "what" and "how" dimensions described by Whetten (1989), it describes new factors that explain the phenomena studied and how they relate to one another. Those new factors, or the "what," are described in terms of the ability of logistical tradeoffs, or the "how," to build resilience.

The third major contribution of this thesis addresses RQ2. The thesis challenges the understanding of resilience in PBS supply chains by investigating building blocks of resilience to meet changed market situations. In doing so, it provides a framework for resilience in PBS supply chains, in which resilience

is developed to be adapted to new boundaries following the COVID-19 pandemic. Answering several calls for more adaptive and transformative resilience and for the alignment of resilience and sustainability, the framework consists of one adaptive and one transformative dimension of resilience. The former constitutes what is generally mentioned in traditional literature on supply chain risk and resilience and relates to Mode 1 of resilience—that is, to adapt the norm. The latter, the transformative dimension of resilience, answers several calls for transformability. To that end, Modes 2 and 3 were developed with the mindset of extending or radically changing service offerings and/or delivery. Accordingly, two steps toward integrating those modes and aligning them with sustainability are presented: the digitalization of the supply chain by leveraging disruptive digital technologies and tools (e.g., the Internet of Things, artificial intelligence, cloud computing, and 3D printing) and utilizing customers' adapted behaviors during the pandemic as leverage to transition toward more remote PBS offerings that encourage the dimension of knowledge.

Acknowledging that transformation in research on resilience, this thesis provides a new perspective on resilience in PBS supply chains by identifying building blocks for resilience that aligns with a configurational approach to theorizing in which multiple attributes are combined into distinct configurations to explain a phenomenon (Cornelissen *et al.,* 2021)—in this thesis's case, resilient PBS supply chains. The multiple explanatory attributes are divided into adaptive and transformative resilience in three modes of resilience, all linked to sustainability as the third attribute of the framework. In that way, the thesis elaborates on the "why" dimension of Whetten's (1989) theory by questioning the assumptions of current research on resilience. The thesis also borrows theories and models from several fields to challenge the underlying rationales. It utilizes the "what" by describing new building blocks and the "how" regarding their relationship to one another (Whetten, 1989). It additionally questions "why" researchers separate resilience and sustainability and answers the question of how those two concepts could be linked to achieve resilient PBS supply chains. The "who–where–when" dimension of Whetten's (1989) work was thus verified in several instances from the three empirical studies performed as a basis for this thesis.

6.2 Managerial implications

OEMs engaged in developing and offering PBSs can now access new tools for cultivating resilience and providing better service offerings and delivery to customers, both in normal and volatile market situations. Along those lines, this thesis takes the perspective on developing resilience beyond logistical tradeoffs with a framework consisting of building blocks for resilient PBS supply chains, ones that incorporate adaptive and transformative resilience measures in three modes of resilience and align them with sustainability.

The thesis showcases how knowledge intensity at the customers' end can reduce dependencies on tangible resources (e.g., spare parts and service personnel), which in turn can reduce environmental

impacts and facilitate resilience in PBS supply chains. Such knowledge can serve as a key enabler to offer a certain level of customer co-creation and self-service, which can consequently support the sustainability-oriented agendas of many companies, many of which have become more offensive and called for new solutions and the improved flexibility, visibility, and velocity of PBS supply chains. That finding reflects experiences from the COVID-19 pandemic, in which remote solutions with decreased transportation have been pivotal for survival in PBS supply chains. In view of that finding, OEMs are encouraged to think beyond what is commonly referred to in the literature on risk and resilience as adaptive resilience and be more transformative in nature as a means to foster transilience. Retuning to original state should not always be the end goal. Instead, OEMs should establish a new, desirable state to work toward during disruptions. The two modes of transformative resilience are fortified as means to achieve that transformation. The framework of resilient PBS supply chains is also complemented with sustainability, which should be all-encompassing throughout all forms of adaptive and transformative resilience.

The above findings and implications for managers can be used to develop PBS offerings and delivery. Going forward, the findings can have implications for policymakers as well. After the COVID-19 pandemic, investments are needed to accelerate toward a more resilient, circular economy that can be integrated into stimulus packages for recovery, especially given the clear shortcomings of linear economies. Additional investments should also be made in PBSs to enhance circularity by slowing resource flows and in cultivating resilience and sustainability to ensure steady PBS offerings and delivery.

6.3 Directions for future research

At the intersection of the resilience framework, between adaptive and transformative resilience and sustainability, reviews and empirical investigations have been few. In addition, the understanding of the relationship between circularity and resilience has been limited, as has the understanding of how circularity, when conducive to deceleration, can improve resilience, and vice versa. This thesis takes a first step toward describing the relationship between those two forces. However, more research on the feasibility and importance of local knowledge is warranted, as is work on what sort of configurations are preferable—for instance, whether products and parts should be limited over people, or vice versa.

Additional research on resilience and sustainability would further clarify the components of the three modes of resilience and establish grounds on which to develop future research involving those concepts. To date, however, empirical research at the intersection of sustainability and resilience, despite being relevant and theoretically beneficial, is exceptionally scarce. Because few organizations have implemented such practices simultaneously, empirical data may be difficult to gather. Nevertheless, it is important to align the two concepts, and given all of the new initiatives supporting their integration, more empirical research is required to understand how that should be done in practice. Understanding

how resilience and sustainability can support each other, as well as their potential conflicts, is also important research for the future. A preliminary question to answer is whether practices are already in place that can contribute to resilience and sustainability and, if so, then how are they measured and understood.

The COVID-19 pandemic has illuminated new avenues for resilient and sustainable supply chain practices, and researchers should seize the opportunity to include sustainable development in their studies on risk and resilience. Sustainability-oriented practices can contribute to supply chain resilience—for instance, by encouraging local suppliers. Sustainability also promotes resource efficiency, which aligns with decreased dependencies on tangible flows. Improved local knowledge, meanwhile, can also boost the resilience and sustainability of PBS supply chains. Altogether, transitioning to sustainable supply chains represents a transformational opportunity to reduce risk and build resilience, and a maturity model for resilience and sustainability that incorporates adaptive and transformative measures should be developed. Ways of measuring resilience and sustainability should be created, as well as ways for how companies should prioritize cultivating both, ideally in research emphasizing the supply chain as the unit of analysis, not the single firm.

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